NATIONAL BUREAU OF STANDARDS REPORT

10 055

DESIGN LOADS FOR INSERTS EMBEDDED IN REINFORCED CONCRETE SLABS

Final Report to
The Construction Research Division
Post Office Department

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 4213417

July 1969

NBS REPORT 10 055

DESIGN LOADS FOR INSERTS EMBEDDED IN REINFORCED CONCRETE SLABS

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SAFE LOADS ON INSERTS EMBEDDED IN REINFORCED CONCRETE SLABS

By T. W. Reichard, E. F. Carpenter and E. V. Leyendecker

1. Introduction

1.1 General

As the cost of construction continues to increase, more and more designers are looking for methods to optimize floor space utilization. One method commonly used is to suspend from the ceiling equipment which might otherwise be occupying premium floor space. An increasing number of devices suitable for suspending such loads are being used in industrial, institutional and commercial buildings.

One such device being used with concrete slab construction is an anchor commonly called a concrete insert. These concrete inserts are made to receive either an ordinary threaded rod or the head of a machine bolt. They are simply fastened to the formwork prior to placing the concrete. This simplicity offers advantages over other devices such as embedded anchor bolts which must penetrate the normally reusable formwork.

Ordinarily, the manufacturer's catalogs are the only source of data regarding the load-carrying capacity of most of these inserts. Table 1 is a listing of such catalog data for some typical inserts made to receive 3/4-inch-diameter threaded rods or bolts.

A recent publication [1][1] presents some load-capacity data for two types of inserts. These data indicate that the load capacity of inserts is partially a function of the length of the inserts. In an investigation of drilled-in anchors, Adams [2] presents data which also indicate that the length of the insert is a major variable. He also shows that the load-carrying capacity of his anchors was a function of the concrete strength. Kennedy and Crawley [3] in a report of an investigation concerning the load capacity of form anchors for mass concrete observed that the failure of the concrete around the anchors was influenced by the bending moments.

As far as is known, no systematic study of the factors which affect the load-carrying capacity of inserts in reinforced concrete slabs has been published. It is known that some manufacturers have investigated certain variables. But, the scope and the results of the tests are not known.

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[1] Numbers in brackets indicate the references listed at the end of this report.

1.2 Objective of Investigation

Due to the limited availability of concrete insert data the Building Research Division, in cooperation with the Post Office Department, conducted a comprehensive study of the variables influencing the ultimate load carrying capacity of some commonly used inserts. The objective of the investigation was to propose design criteria for inserts embedded in reinforced concrete slabs such as those found in postal facilities.

The following variables were studied:

a) Insert type
b) Concrete aggregate type
c) Concrete strength
d) Reinforcement cover
e) Reinforcement spacing
f) Angular load effect
    1. Angular displacement of insert
    2. Angular insert load
g) Bending moment magnitude
h) Sustained load
i) Fatigue loading

2. Test Materials

2.1. Inserts

Three different inserts were used in the main part of the investigation. In preliminary tests [4], eight different inserts were used, but the number was reduced to three for

this study to satisfy a Post Office Department specification requiring malleable iron inserts suitable for attaching 3/4-inch diameter threaded rods. Two of the deleted types were made from gray cast iron; two were for use with machine bolts or nuts, and one was a special insert made especially for thin slabs.

In general, concrete inserts are made from a metal suitable for casting. Some, especially the smaller sizes, are made from die-casting alloys. But, most are made from either gray cast iron or a white cast iron suitable for malleablizing. A few manufacturers produce inserts machined from mild steel, or even shaped from sheet steel. The intrinsic advantage of steel or malleable iron over brittle cast iron for inserts is obvious. However, the cast iron inserts are lower in cost than the malleable, so the choice is usually dictated by the expected loading conditions.

2.1.1 Type 1 Inserts

The Type 1 insert used in this investigation is described in the catalogs as a malleable iron threaded insert, especially designed for use where impact or vibration is a factor. Figure 1 is a photograph of this insert, and it indicates the significant dimensions. These inserts were fastened to the

plywood concrete form with 1" roofing nails driven through the two side lugs.

2.1.2 Type 2 Insert

The Type 2 insert illustrated in Figure 2, is called a threaded insert by the manufacturer. The closed end spool is machined from mild steel. The loop welded to the spool is 0.26 in. diameter steel wire, with an ultimate strength of about 65,000 psi. These inserts are set in the concrete form by using a plastic plug or cup which is nailed to the form prior to forcing the insert over the cup.

2.1.3 Type 3 Insert

The Type 3 insert illustrated in Figure 3 is also called a threaded insert by the manufacturer. The insert used in this investigation was made from malleable iron, although the manufacturer does produce a similar insert made from gray cast iron. These inserts were set by driving one-inch roofing nails through the two side lugs into the form.

2.2 Concrete

Table 2 describes the seven types of aggregates used in making the concrete. As indicated in this table, two of the coarse aggregates were normal-weight and five were expanded-shale lightweight aggregates. All concretes were mixed in 6-10 cu. yd. commercial transit mixers in 3 cu. yd. batches or larger. The normal weight concretes were standard mixes for the supplier, as were the concretes made with the L-1 lightweight aggregates. For the concretes made with L-2, L-3, L-4, and L-5 lightweight aggregates, the readymix contractor supplied the cement and usually the sand. The lightweight aggregate was measured and placed in the mixer by NBS personnel. These concretes were proportioned as recommended by the aggregate producer, except that water was added until a suitable consistency was attained. A 4-6 in. slump was the target consistency for the normal-weight concrete, and a 2-4 in. slump for the lightweight aggregate concrete.

Some problems were encountered in acquiring the desired density and consistancy with the readymix L-1 semi-lightweight concrete. These problems were probably a result of the rather small batch sizes in the large mixers.

Control cylinders (6-x 12-in.) were cast from each batch of concrete for compressive and splitting strength determinations. All specimens were consolidated in the mold by internal vibration. After removal from the molds, all specimens were air-dried until tested. The specimens were tested at various ages, ranging from 5 to as much as 35 days or more. Compressive strength determinations were made in accordance with ASTM Method C-39. The splitting tensile strength determinations were made in accordance with ASTM T-496, except for the curing conditions.

2.2.1 Normal-Weight Aggregate concrete

Table 3 gives the properties of the concrete mixes made with normal-weight aggregates. The sand-stone ratio was 45-55 for all mixes except H-2 and H-2a. For these two mixes the proportions were 40-60.

Table 4 is a resume' of the compressive and splitting strength determinations made on each normal-weight concrete.

2.2.2 Lightweight Aggregate Concrete

Table 5 is a listing of the concretes made with the lightweight aggregates. These concretes were all semi-lightweight[2] except for L-4. The proportions recommended by the producer of the lightweight aggregate were used throughout this investigation.

Table 6 lists the results of the strength determinations on these lightweight aggregate concretes.

2.3 Reinforcement

All principal reinforcement was No. 5 deformed, intermediate-grade steel bars placed on bolsters to provide the required concrete cover. Temperature steel was generally No. 3 bars spaced at about 12 in. on centers.

2.4 Test Specimens

Four general types of concrete test specimens were used for the inserts in this investigation. Except for one waffle slab all specimens were 4 1/2" thick and were designed as

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[2] Semi-lightweight concrete is a concrete containing the coarse lightweight aggregate, but with a natural sand replacing the lightweight aggregate fines.

one-way slabs. The length and width were dictated by the purpose for which it was made. All 4 1/2" thick specimens were cast in wood forms, with the inserts nailed to the bottom of the form. The specimens were turned over for testing.

2.4.1 4x4 Specimens

Ninety percent of the almost 400 specimens tested were the nominal 4x4 specimens. A single insert was cast in the specimen, with the reinforcement placed symmetrically about the insert, and with the principal steel placed parallel to the long dimension, with 3/4 in. cover. The actual dimensions of the specimen were 42 in. x 45 in. x 4 1/2 in. thick. This specimen size was arrived at after the preliminary test [4] indicated that a smaller specimen would not be staisfactory for single insert pull-out tests.

Figure 4 is a photograph of a static pull-out test on a 4x4 specimen and illustrates a typical failure of the concrete. It is obvious that, if the test-stand supports were closer together, the failure zone would be changed.

2.4.2 4x22 Specimens

Seven 4x22 specimens were cast with a width of 42 in. and a length of 22 ft. The principal reinforcement in all these slabs was No. 5 bars at 6 in. on centers and with 3/4 in. cover. Four of the seven specimens were designed as one-way slabs to be continuous over three supports with two 10 ft. spans. Negative reinforcement for these slabs was No. 5 bars at 8 in. on center, placed with 3/4 in. cover from the top surface as cast. Nineteen inserts were cast, in each continuous slab at about 12 in. on center. These slabs were cast from concrete designated as S-1, 2, 3, and 4. In addition to the long slabs, four companion 4x4 slabs with single inserts were cast, with the S-1, 2, and 3 concretes.

Figure 5 illustrates a 4x22 continuous slab ready for a test to determine the effect of bending moment on the pull-out strength of the insert. The positions of the 19 inserts are indicated by the eyebolts. It should be noted that, although the specimens were cast in the orientation they would be on the job, all slabs were turned over for testing.

Three additional 4x22 specimens, designed as simple span, one-way slabs, were tested with a 20 ft. span to investigate the pull-out strength of inserts in long thin slabs. Five

inserts were cast in each of these specimens. One insert was at mid-span, two were at 30 in. on either side of mid-span, and two were at 31 in. from either end. The two inserts near the ends were tested as if they had been cast as separate 4x4 control specimens. These three specimens were cast from concrete designated as X-20A, B, and C.

2.4.3 4x16 Slab Specimens

The longer 4x16 fatigue test specimens with a width of 45 in. and a length of 15 ft. 9 in. were cast from the X2-A, B, C, and D concretes. Four specimens containing Type #3 inserts were cast from each concrete. The inserts were spaced so that each specimen had two inserts, spaced at 64 in. from either end, available for fatigue tests on a 10 ft. span. In addition, each specimen contained inserts placed at 24 in. from either end, for simulated pull-out 4x4 tests. Figure 6 is a photograph of a 4x16 specimen prior to placement of the concrete. The two top bars visible in this picture were for prevention of damage while handling. These specimens were made in order to determine the effect of bending moment on the pull-out strength of inserts subject to cyclic fatigue loading.

2.4.4 Waffle Slab Specimen

A single waffle slab specimen with overall dimensions of 6 ft. x15 ft. x12in. was cast from the normal-weight concrete designated as W-1, using 10 in. deep 30in. x30in. metal pans. Figure 7 is a photograph of the waffle slab prior to placement of the concrete. Two No. 5 bars were placed 3/4" from the bottom of each 6" rib in the long direction, and two No. 5 bars were placed on top of these in the opposite direction. Welded wire fabric (66-1010) was placed over the pans. Inserts were placed at each of the interior intersections (36 in on centers) of the ribs.

3. Test Apparatus

3.1 Static Test Equipment

Figures 4, 5, and 8 illustrate the apparatus used for applying short-term static pull-out loads to the inserts embedded in the concrete specimens. The apparatus in Figure 4 was used for the 4x4 specimens, while that in Figure 5 and 8 was used for the 4x22 specimens. The basic parts were:

a) a steel stand with supports spaced at the required distance;

b) a center-hole, 60-kip hydraulic ram powered with a remote hand-operated pump;

c) a center-hole 60-kip load cell;

d) an X-Y plotter for recording the output of the load cell; and

e) a 3/4" high-strength steel pull-rod.

When testing the 4x4 specimens, the test stand had an effective span of 42". The effective span of the stand for the longer specimens was the same as the span of the test specimen. The test stand was always placed so that its span was in the same direction as the main reinforcement.

For some tests, the vertical movement of the insert relative to the transverse edges of the concrete specimen was measured by using an LVDT displacement transducer. The LVDT visible in Figure 8, was mounted on the pull-rod, and the core rested on a bridge, supported at the mid-span edges of the slab. The output of the LVDT was fed to the X-axis of the X-Y plotter used with the load cell so that a continuous plot of the load versus vertical movement data was recorded.

3.2 Sustained Load Equipment

The sustained load equipment was designed to hold a constant tensile load on inserts embedded in 4x4 specimens. Figure 9 is a picture of some of the specimens under sustained load. Essentially, the sustained loading equipment was the same as the static load equipment, except that a 15-kip spring was used in place of the hydraulic ram. The spring, which was used to provide the required sustained load, was compressed by using the 60-kip ram. The load developed by the compressed spring was measured with the load cell and adjusted periodically. Movement of the pull-rod relative to the transverse edges of each specimen was measured with 0.001-in. dial gauges, which are visible in Figure 9.

3.3 Fatigue Loading Equipment

Figure 10 is a general view of the fatigue tests on two 4x16 specimens. Alternating tensile loads of the required magnitude were applied by 10-kip servo-controlled hydraulic rams, reacting against a steel frame bolted to the laboratory tie-down floor. The test specimens were held to the tie-down floor at their reaction points. Both 4x16 and 4x4 specimens were tested under fatigue loading. The 4x16 specimen pictured in Figure 10 was

tested with a span of 10'. The test span for the fatigue tests on the 4x4 specimen was 42". Two fatigue tests were made on each 4x16 specimen, but only one on each 4x4 specimen.

4. Test Procedures

4.1 Static Tests on 4x4 Specimens

The testing procedure was rather simple for the short-term static tests. The tensile pull-out load was applied to the insert at a uniform rate, until failure occurred. The maximum load attained during the tests was called the pull-out load of the insert in a 4x4 specimen (P_4). During preliminary tests, there were indications that the maximum load was a function of the rate of loading. For that reason, a standard loading rate of 2-kips per minute was established for the static tests.

Figure 11 is typical load-movement data for Type #1 inserts. The movement plotted in this figure is the movement of the pull-rod relative to the mid-span edges of the concrete slab. Typical specimen failures are illustrated in Figures 4 and 12. In general, the size of the pull-out cone was about the same size for the Type #1 insert as for the Type #3, but smaller in area for the Type #2. Types #1 and #3 inserts did not appear to be damaged by the tests. However, in about 70%

of the tests, the wire loop of the Type #2 insert failed near the point where it was welded to the spool. Even when the loop did not fracture, the loop wires were visibly necked down.

4.2 Static Flexural Tests

4.2.1 Continuous 4x22 Slab Specimens

The continuous 4x22 slabs made from concretes designated as C-1, 2, 3, and 4 were tested in the manner indicated by Figures 5 and 8. Only partially visible in Figure 5 is an air-bag system underneath the slabs. Prior to the pull-out tests, the air pressure in the air bag was adjusted to provide a uniform distributed load of 90 psf. This load is equal to a floor load of 30 psf plus 60 psf which is half the design load for inserts.

It should be noted that not all the 19 inserts shown in Figures 5 and 8 were pulled. Generally, every other insert was pulled, until failure, and then the balance were pulled out. However, many times, the first pull-out damaged the specimen in such a manner that the neighboring inserts might have been affected. When this happened, the neighboring inserts were not pulled.

The companion 4x4 specimens were tested using the regular static test procedure at the same age as the 4x22 specimens.

4.2.2 Simple Span 4x22 Slab Specimens

The three 4x22 specimens were cast from concretes designated as X20-A, B, and C. They were tested with a span of 20-ft. in a manner similar to that used for the continuous slabs, except that due to the smaller load capacity no simulated live load was provided by an air-bag system. Each of these slabs contained only five inserts. The two inserts near the end were tested after the mid-span inserts had been pulled, and they were tested as if they were in 4x4 specimens.

4.2.3 Waffle Slab Specimens

Four Type #3 inserts were embedded in the waffle slab concrete at the four interior intersections of the 6-in. ribs, as shown in Figure 7. The intent of the test was to determine if the pull-out strength of inserts embedded in a waffle slab was affected by the relatively thin section of concrete around the insert. It should be noted that standard practice usually results in the placement of two reinforcement bars in both directions at the bottom of the ribs. This practice, which was followed for this test, results in the inserts being positioned so that the bars are close to the insert on the four sides. The inserts were tested using the 42-in. test-stand placed on the transverse ribs.

Figure 13 is a photograph of the waffle slab after testing. The crack pattern, accentuated by felt pen-markings, is easily visible in this figure and shows how the cracks tended to extend along the line just below the reinforcement. There is no doubt that the inserts were restrained by the reinforcement, as evidenced by the crack patterns in the ribs.

4.3 Sustained Load Tests

Four batches of concretes, designated as C-1, 2, 3, and 4, were used in preparing the 4x4 specimens used in the sustained load tests. C-1 and C-3 specimens were normal-weight concrete, and C-2 and C-4 were semi-lightweight concrete. The purpose of the tests was to determine the maximum load which can be carried by an insert for an indefinitely long period of time.

Two types of sustained load tests were attempted. The first type of test consisted of slowly increasing the load at a constant rate, until failure occurred.[3] The rate of loading was varied from 0.45 kips/hr. to 2.0 kips/min. so as to get a relationship between failure load and rate of loading.

[3] This loading scheme is a modification of the "Prot Method" [5] sometimes used in the cyclic fatigue testing.

Although inconclusive, the data indicate that the sustained pull-out strength would reach a minimum of about 90% of the short-term strength, at a rate of about 0.1 kips/hr. At a slower rate of loading the indication is that the sustained strength may become greater. This unexpected indication requires further study for verification.

The second type of sustained load test, and the more conventional, consisted of applying a predetermined pull-out load on the insert and maintaining it constant. The load was maintained using the springs visible in Figure 9. The magnitude of the load to be sustained was determined after ordinary short-term static pull-out tests were performed on companion 4x4 specimens. The sustained loads applied were 80, 85, and 90% of the short-term pull-out loads. The movement of the pull-out relative to the edge of the specimen, which included some deflection of the slab, was measured at intervals of time, so that creep movement vs. time could be plotted. Typical failure in the sustained load test is shown in Figure 14.

4.4 Fatigue Tests

4.4.1 General

Two series of fatigue tests were made on inserts embedded in 4 1/2" thick slabs. The first series of tests were on inserts embedded in 4x4 slabs, while the second series were on inserts embedded in 4x16 slabs.

One of the most important variables in fatigue tests is the range of the cyclic portion of the test load. This range (R) is usually expressed as the ratio of the minimum to the maximum load. Murdock and Kessler [6] have shown that, for plain concrete in flexure, the fatigue strength (10 million cycles) is about 55% of the static short-term strength, when R=0.0 When R=0.3, the fatigue strength is about 65%, and when R=0.6, the fatigue strength is about 80%.

4.4.2 Fatigue Tests on 4x4 Specimens

Twelve 4x4 fatigue test specimens were cast from each of the F-1, 2, 3, and 4 concretes. Type 1 inserts were cast in the F-1, F-2, and F-3 specimens. Four inserts of each of the three types were cast in the F-4 slabs. The strength of the

F-1 specimens was so great that the fatigue tests could not be made with the available equipment. These 4x4 specimens were fatigue loaded on a span of 42", with a minimum load (P min) of 3.0 kips for all specimens. The maximum load (P max) was varied so that P min/P max (R) varied from 0.30 to about 0.43.

4.4.3 Fatigue Tests on 4x16 Specimens

Longer fatigue test specimens were cast from the X2-A, B, C, and D concretes. Four specimens containing Type #3 inserts were cast from each concrete. The inserts were spaced so that each specimen had two inserts available for fatigue tests on a 10-ft. span. Thus a total of eight fatigue tests were made on specimens from each concrete. These fatigue specimens also contained inserts at either end for determination of the static strength in a 4x4 specimen (Figure 10). The maximum and minimum load values were varied, but their range (R) was held constant at 0.63 for these tests. It should be remembered that this range is less severe than that used for the 4x4 slabs of section 4.4.2.

5.0 DISCUSSION OF RESULTS

5.1 Decision Path Flow Chart

Ideally a test program directed toward design recommendations should be statistically rigorous. However, in actual practice most design criteria relies heavily on engineering judgment supplemented by tests. Since this study falls within the latter category, an attempt has been made to sharpen the engineering judgment process by the use of decision path flow charts. One such chart is illustrated by Figure 15. This flow chart describes the test and decision sequence used to develop design recommendations and is included as an "overview" to the discussion of Sections 5 and 6.

5.2 Effect of Aggregate and Insert Type

Table 7 lists the results of tests performed on 4x4 specimens during the early stages of the investigation. In order to minimize project complexity, these initial results were used to make statistical inferences in deciding whether to emphasize aggregate-type or insert-type as the more significant parameter.

Since concrete L-4 was the only fully lightweight concrete (lightweight fines and lightweight coarse), it was deleted from the statistical observations used to compare normal weight concrete and semi-lightweight concrete (lightweight coarse only). Note that the results of tests on Type L-4 were significantly lower than the tests on semi-lightweight concrete of comparable strength. This suggests that data for semi-lightweight concrete should not be directly extrapolated to fully lightweight concrete without additional testing. Table 8 summarizes some elementary statistics computed to show the relationship between the insert type and the concrete type. Referring to these statistics, it was decided that a two-part partitioning of the test distribution into normal and semi-lightweight concrete would be the most meaningful. (See Sect. 5.9) Insert Type 3 was selected as the reference insert to which the other two could be compared, when such comparison was warranted.

5.3 Concrete Strength-Weight Effects

Figures 16 and 17 show plots of 4x4 specimen pull-out load (P_4) vs. the square root of concrete compressive strength ($\sqrt{f_c'}$) for normal and semi-lightweight concrete. The plotted

data includes the results of all static tests (about 200) performed on 4x4 specimens.

A computer program was written to perform the following statistical analysis: [7 and 8]

(a) Perform a linear regression analysis (least square-fit method) to determine coefficients of the regression equation and estimated variance of the slope and intercept.

(b) Test the hypothesis of linearity, assuming a functional relationship and using the "F" distribution.

(c) Determine the confidence band for the line as a whole using percentiles of the F distribution.

(d) Determine the confidence interval estimate for a single value of P at a given value of $\sqrt{f_c'}$, using Student's "t" distribution.

(e) Assuming the two dimensional relationship functional, transform all values of P to an equivalent, normalized value (P_n) at a given concrete strength (f_c'=3000psi).

(f) Calculate the sample mean and deviation of the normalized distribution.

For the normal-weight concrete (Figure 16), the regression equation is given by:

$$P_{4h}=1.63+0.18\sqrt{f_c'} \quad \text{- - - - - - - -} \quad 5.3(1)$$

with estimated deviation of intercept, S_a=1.3

and estimated deviation of slope, S_b= 0.02.

Where P_{4h} is insert pull-out strength in normal weight 4x4 specimens (kips).

For the semi-lightweight concrete (Figure 17), the regression equation is given by:

$$P_{4s}=3.1+0.13\sqrt{f_c'} \text{ - - - - - - } 5.3(2)$$

with estimated deviation of intercept, $S_a = 1.5$, and the estimated deviation of slope, $S_b = 0.02$.

Where P_{4s} is the insert pull-out strength in semi-lightweight 4x4 concrete specimen.

The dashed curved lines shown on Figures 16 and 17 represent the 95% confidence band of the regression line. In other words, if all the tests were repeated 100 times, then at least 95 of the 100 regression lines would be in the region bounded by the dashed lines. Thus the narrowness of the region between confidence bands is a statistical measure of reliability for the regression equation.

Confidence band determination for the whole line is based on using the "F" distribution with 2 degrees of freedom in the numerator and (n-2) degrees of freedom in the denominator where n is the number of points. Because the confidence band interval makes joint statements about two dimensions then the interval of the whole line will be greater than a point confidence interval by the ratio $\sqrt{2F}/t$. Using confidence intervals to predict reliability

requires that the assumptions associated with the F distribution be reasonably accurate. Since the F distribution is the ratio of two quantities independently distributed by chi-square laws, it follows that the sample distribution should be normally and independently distributed.

In comparing Figures 16 and 17, it is reassuring to note the statistical similarity of the two sets of tests. It is also interesting to introduce the relative effects of concrete unit weight. The average unit weight of the normal-weight concrete (W_h) was 142 lbs./cu. ft. The average unit weight of the semi-lightweight concrete (W_h) was 118 lbs./cu. ft. Thus the ratio of unit weight (W_h/W_s) is 1.20. For 3,300 psi concrete, the calculated regression equations give:

$$P_{4h}=1.63+0.18\sqrt{3,300}=12.0 \text{ kips.} \quad - - - \quad 5.3(3)$$

$$P_{4s}=3.1+0.13\sqrt{3,300}=10.5 \text{ kips.} \quad - - - \quad 5.3(4)$$

Since $P_{4h}/P_{4s}=1.15$ is close to the unit weight ratio of 1.20, there may be a linear proportionality relationship between concrete unit weight and the insert pull-out strength. To investigate this possibility, consider the nine tests on concrete L-4. For this lightweight concrete, the unit weight (W_1) was 96 lbs./cu. ft., and the concrete strength was 3,300 psi. If the unit weight ratio is a good approximation, then the average pull-out strength of these tests should be 8.1 kips.

The experimental average of the nine tests was 8.3 kips. Although the results of nine tests is insufficient data to form a final conclusion for the lightweight, the available evidence points toward a generalized ultimate insert pull-out strength equation of the form:

$$P_{4u}=2{,}000+1.2W_c\sqrt{f_c'} \quad - - - - \quad 5.3(6)$$

where P_{4u} is the insert pull-out strength in 4x4 specimen (lbs)

W_c is the unit weight of concrete (pcf)

f_c' is the cylinder strength of concrete (psi)

Based on this equation theoretical ultimate insert pull-out strengths have been calculated for 3,000 and 5,000 psi concrete. Table 10 compares these theoretical results with experimental averages. As can be seen, the comparison is well within acceptable limits.

5.4 Effect of Flexural Tension

Insert pull-out strength is dependent largely on the tensile capacity of the embedding concrete. If this capacity is reduced by tensile cracking resulting from flexural action, then insert pull-out strength would decrease. In the case of a 4x4 specimen, the slab moment at the insert pull-out failure is in the order of one half the ultimate moment capacity of the slab.

To study the effects of slab bending moment on insert strength, three longer slabs (4x22 specimens) were constructed with inserts on 12 in. centers. These slabs were supported at three reaction points on 10 ft. centers to simulate the condition of a 4 1/2 in. thick slab continuous over two spans. Simulation of a uniform live floor load of 90 lbs./sq. ft. was accomplished using air bags. Figure 5 shows the test set-up. One additional continuous slab specimen was tested with uniform live floor load of 150 lbs/sq. ft.

Figures 18, 19, and 20 show the results of the insert pull-out tests performed on the three continuous slabs with 90 lbs/sq. ft. floor load. Slab #1, shown by Figure 18, contained Type-1 inserts. Slab #2, shown by Figure 19, contained Type-2 inserts, and Slab #3 of Figure 20 contained Type-3 inserts. Four control tests were performed on 4x4 specimens for each continuous slab. The average of the control tests is represented on the respective figures by a horizontal line.

Figure 21 is a plot of all insert tests performed for the four continuous slabs; with the ordinate being the pull-out load (P') and the abscissa being the calculated moment the pull-out load for each insert. For small moments, the increased pull-out strength can be attributed largely to the

containing influence of reaction supports. For moments larger than 15 kip-ft. the inserts are more than 15 inches from a reaction support and since the insert pull-out cone varied from 12 in. to 20 in. diameter it is unlikely that reaction supports affected those inserts with moments larger than 15 kip-ft. The experimental scatter in Figure 21 makes it difficult to assess the effect of moment on pull-out strength, even though Figures 18, 19 and 20 indicate that such an effect exists. To form some conservative conclusion it seems reasonable to refer back to these three figures for additional information.

Comparison of Figures 18, 19, and 20 shows consistent recurrence of a positional effect on insert pull-out strength, P'. Since this positional factor has the form of an influence curve, and since the concrete tensile cracking is a function of moment, it seems logical to plot average pull-out load against the average slab moment at insert failure (M_f). Average slab moment is defined as the static moment (M_f) at the insert location due to applied uniform load and the average pull-out load on the insert.

To eliminate the magnification of statistical error, the six curves of Figures 18, 19, and 20 were reproduced

and averaged. The average values were used to calculate and plot the Load-Moment relations shown in Figure 22. Figure 22 shows two distinct curves, one for the tests performed near the end reaction-point, and one for the set of tests performed nearer the middle reaction point. The spread between these two curves is attributed to the inaccuracies of theoretical assumptions such as: uncracked continuity over the center support and knife-edge reaction points. If it were analytically possible to account for the small error in these assumptions, the effect would be to pull the two curves toward each other. This is confirmed by a consideration of the test procedure and also by plotting the average of the twelve 4x4 control specimens and noting that the resultant point falls between the curves. Also shown on this figure is the ultimate moment capacity of the slab, (M_u), calculated in accordance with ACI 318-63. As expected, the insert pull-out strength decreased more rapidly for the moments approaching the ultimate capacity of the concrete slab.

5.5 Effect of Reinforcement Cover and Spacing

5.5.1 Concrete Cover

Table 9 lists the results of tests performed to study the effects of reinforcement spacing and concrete cover.

Test specimens were the 4x4 concrete slabs with insert Type-3. Test No. X-1B-1 through X-1B-9 were performed as three sets of three tests, each set with a different amount of concrete cover (3/4 in., 1 1/2 in., and 3 in.) over the reinforcing steel. Reinforcement for each set consisted of #5 bars at 12 in. c/c to simulate a condition of minimum reinforcement. In addition, a fourth control set was included with #5 bars at 6 in. c/c, to reference the minimum reinforcement condition with a more common design situation.

Detailed consideration of concrete cover effects can be established by referring to Figure 23, which is a plot of insert pull-out strength vs. concrete cover for the three test sets of concern.

Changing the concrete cover from 3/4 in. to 1 1/2 in. reduces the insert pull-out loads by about 10%. As discussed in Section 5.4, such a loss is to be expected because of the decrease in slab moment capacity. The relative effects of the two parameters (concrete cover and moment capacity) are discussed in more detail in Section 6.4.

5.5.2 Reinforcement Spacing

Referring again to Table 9, Tests No. X-1A-1 through X-1A-12 were designed to study the effects of reinforcement

spacing. Tests No. X-1A-1 through X-1A-9 were performed as three sets of three tests, each set with a different steel spacing (3-1/2 in., 6 in., 12 in.). The concrete cover and percent reinforcement was held approximately constant. From the test results, it is observed that up to 12 in. spacing the steel location does not significantly affect insert strength.

The fourth set of three tests was designed to approximate the non-reinforced situation. The results of these tests are significantly lower than those for the reinforced concrete. As in the case of extreme concrete cover, these tests are in effect measuring the moment capacity of the slab, rather than the insert pull-out strength in unreinforced mass concrete. In other words, reinforcement yielding occurs prior to insert failure.

5.5.3 Waffle Slab Ribs

The single waffle slab (W-1) test was made to determine if the pull-out strength of an insert would be affected by the relatively thin section of concrete around the insert.

The average pull-out load for the four-Type 3 inserts was 15.5 kips. These results indicate that the pull-out strength of inserts embedded at the intersection of 6 in. ribs in

similar waffle slabs would be as good or better than that for those embedded in the 4x4 specimens. It should be noted that the position of the reinforcement relative to the insert is probably an important variable.

5.6 Sustained Load Behavior

To study the effect of sustained load on insert pull-out strength, eighteen 4x4 specimens were tested. Nine of these were made from normal-weight concrete and nine of semi-lightweight concrete. Type 1 and Type 3 inserts were used. The results showed that sustained load effects were not significant enough to be concerned with the effect on Type 2 inserts.

For each type of concrete, the nine tests were subdivided into three groups of three tests. Each of the three groups were tested at different sustained load levels. These load levels were 80%, 85%, and 90% of the insert pull-out strength obtained by performing static tests to failure on companion 4x4 specimens. The static control tests were made at the beginning of the sustained load time interval.

The results of the sustained load tests are plotted on Figure 24, as Time vs. Deformation curves. Each of the six curves represents the average of the three tests performed at the indicated load level. The dashed curves represent semi-lightweight concrete, while the solid lines apply to normal-weight concrete. As shown on the figure, the only failure occurred for semi-lightweight concrete loaded to 90% of the equivalent static strength. For all other load levels, the deformations are relatively small, stable, and tending toward an asymptotic relationship with respect to some upper-bound deformation.

5.7 Fatigue Load Behavior

5.7.0 General

To study the effects of fatigue loading on insert pull-out strength, approximately 50 fatigue tests were performed. Of these tests, 25 were performed on Type 3 inserts embedded in the 4x16 specimens and tested with a beam span of 10 ft. The remaining 25 tests were performed on the three types of inserts embedded in 4x4 specimens. Each type of fatigue test slab had 4x4 static control test specimens so that fatigue loads could be expressed as a ratio of the static strength (P_{max}/P_4).

5.7.1 Normal-Weight Concrete

Figure 25 is a semi-log plot of P_{max}/P_4 vs. number of cycles causing fatigue failure. These tests were performed on Type 3 inserts embedded in slabs made from two batches of normal-weight concrete. The range of the cyclic load ($R=P_{min}/P_{max}$) was held constant at 0.63.

The averages of the 4x4 static control tests for the two batches were 11.6 kips, and 13.7 kips, which is close to the mean load of all static tests at similar concrete strengths.

The fatigue test results shown in Figure 25 indicate that the fatigue strength at 2 million cycles is about 65% of the static strength for the 4x4 control specimens. In short-term static tests on companion specimens with a 10 ft. span the insert strength was 87% of the strength for the 4x4 control specimens. This suggests that about 1/3 of the apparent strength loss in these fatigue tests was due to the increased span and 2/3 was due to fatigue.

In general the fatigue test slabs were reinforced by #5 at 6 in. c/c. To check the effect of reinforcement spacing on fatigue strength, one test slab from each batch was reinforced with #5 at 12 in. c/c. As indicated on

Figure 25, the reduction in steel did not significantly reduce the insert fatigue strength.

5.7.2 Semi-Lightweight Concrete

The results of fatigue tests with semi-lightweight concrete specimens are plotted in Figure 26. These tests were similar to those of Figure 25, except that the test specimens were made from two batches of semi-lightweight concrete. Type 3 inserts were embedded in the slabs.

The average pull-out strength of the 4x4 static control tests was 10.8 kips, which is close to the mean load of all 4x4 semi-lightweight tests.

The fatigue test results shown in Figure 26 indicate that for 2 million cycles, the fatigue strength of an insert is about 70% of the static strength for the 4x4 control specimens.

In static tests on companion specimens with a 10 ft. span the insert strength was 89% of the strength for the 4x4 control specimens. Again we have a suggestion that about 1/3 of the strength loss in these fatigue tests was due to the increased span and 2/3 was due to fatigue.

5.7.3 Relation of Insert-Type to Fatigue Strength

Figure 27 shows the results of 25 fatigue tests performed on inserts embedded in 4x4 specimens. These less expensive tests were used to investigate the effect of insert type on fatigue strength. A secondary consideration involved comparing the fatigue relationship of semi-lightweight to normal-weight concrete with insert Type 1.

A first view of Figure 27 suggests that insert type-#2 tested 10% higher than Type 3 and 20% higher than Type 1. But, recall that Table 7 shows the static strength of insert Type 2 to be 20% lower than Type 1, and it becomes apparent that the two differential effects offset each other. Thus, in the absolute sense, there is no significant difference between the inserts in fatigue loading.

Figure 27 also shows that the semi-lightweight concrete has a P_{max}/P_4 ratio slightly greater than that for normal-weight concrete. This agrees with a similar observation of Figures 25 and 26 and shows that it holds for insert Type 1, as well as Type 3.

5.7.4 Fatigue Failures in Connecting Hardware

An important adjunct to the fatigue testing on the inserts was the discovery that the fatigue limit for some of the connecting hardware used in the tests was close to that of the actual test specimens being tested. No record was kept of the individual eyebolts and clevis pins so that the full history of each is not known. However, the mortality rate for this hardware was around 50% of that for the insert specimens.

This is not surprising when fatigue data, such as has been presented in [9], is considered. These data indicate that the fatigue strength of ordinary steel bolts can be as low as 20.0 ksi for 10 million cycles. This means that, for a safety factor of 2.0, the allowable load under cyclic loading conditions on a 3/4 in. steel bolt could be as low as 3.0 kips.

5.8 Angular Load Effect

Referring to Table 11, Tests No. X-4A-1 through X-4A-12 were designed to investigate the effects of intentional or unintentional misalignment of an insert or its connecting hardware. Tests X-4A-1 through X-4A-4 were performed on well-aligned inserts and loads, for

reference purposes. Tests X-4A-5 through X-4A-8 were performed to determine if an angled load decreased the insert pull-out strength. The results show no reduction in strength.

Tests X-4A-9 through X-4A-11 were performed to establish if an angled insert decreased the pull-out strength. The results show no reduction in strength. Test X-4A-12 was an angled insert with an aligned load. Again, there was no reduction in strength.

5.9 Statistical Observations on 4x4 Tests

To be rigorous, statistical tests and inferences should be based on guaranteed randomness. Unfortunately this investigation, like many engineering studies, cannot afford the security of random sampling. A practical substitute is to conceptualize random sampling by introducing "engineered randomness". This allows an engineer, familiar with the physical behavior and conversant with statistical methods, to simulate random sampling by carefully selecting a set of samples that best represent the statistics of concern. The success of such a process depends on the ability to apply prior knowledge and having the means to test the validity of final results. This imposes the restriction that statistical

applications be kept so elementary that the analyst can continuously monitor important results by a comparison with the real situation.

About two hundred static 4x4 tests were performed during the overall study. Many of these 4x4 specimens were used as control samples for the investigation of the various parameters. Figure 28 is a histogram of all 4x4 static pull-out tests performed, regardless of the concrete type or insert type. This histogram is irregular, with no clearly-defined sample distribution. The sample lot has a mean value of 12 kips, and a standard deviation of 2.5. The non-parametric tolerance limits enable one to say with 99% confidence that 95% of the population lies in the region of 12 ± 5 kips. In order to improve the statistical reliability, it is necessary to treat this data as something other than a sample from one large monovariate population. A multivariate representation of the population could be a statistically valid alternative; however, the additional complexity in interpretation would impede comparison with the physical situation.

As mentioned in Section 5.2, the total sample can be subdivided into as many as six sample sets, each representing a particular type of insert in a particular type of concrete. Given a choice of subdividing the

total sample space into subsets of either insert type or concrete type; one can use the statistical observations of Table 8 for guidance. This can most readily be done by calculating the estimated standard deviation of the various alternative distributions and selecting the subsectioning method that minimizes variance and maximizes mean differences. Since the range (R) divided by the square root of "n", the sample size, is a good estimator for sample deviation of small lots, it is apparent from Table 8 that variance is not as significant a consideration as the difference between means in deciding how to partition. Of course this can be confirmed by using the more accurate "maximum likelihood estimator" to estimate variance.

The other decision mentioned in Section 5.2 was the selection of Type 3 insert as most representative of the three types. This choice again was validated by comparing the average performance (one-sided normal test) and by comparing variability of performance (one-sided F test) for the three insert types.

Figures 29 and 30 are histograms showing the distribution of all 4x4 tests performed with normal-weight and semi-lightweight concrete, respectively. As can be observed, both distributions exhibit kurtosis and are positively skewed,

indicating that a parameter other than experimental deviation is affecting the distribution. The discussion of Section 5.4 shows this skewed property to be a function of concrete strength. In order to develop a conservative estimate of mean and variance the skewness should be eliminated, if possible.

To interrelate the results of all tests, it is necessary to first establish a relevant standard to which all tests can be related. Thus the objective becomes to estimate as accurately as possible the mean value and deviation of all 4x4 insert pull-out tests for 3,000 psi concrete. In order to take full advantage of all two hundred 4x4 tests, some method must be used to neutralize the effect of concrete strength on the pull-out load. One simple and direct technique is to transform the linear bivariate relations of Figures 16 and 17 into a representative normalized monovariate distribution, free of concrete strength effects.

Because of the cumulative property of the normal distribution, it may be theoretically valid to make this transformation simply by selecting a reference concrete strength and making use of the

regression equation to calculate the equivalent pull-out loads, as though the tests had all been performed at one concrete strength. This procedure depends on the assumption that the sample distribution at any particular concrete strength is drawn from the normal and with a variance not significantly affected by the magnitude of concrete strength. Furthermore, if the resulting modified cumulative monovariate sample is truly representative, with a distribution affected mainly by experimental scatter, it is likely to have the form of a normal distribution. This allows one to test the quality of the "engineered randomness" by testing the results against the knowledge that the mean of a random sample drawn from the normal population is itself a variate with normal density, $N(\mu,\sigma^2/n)$.

Figures 31 and 32 are histograms of all 4x4 tests transformed to the 3,000 psi equivalent load. Figure 31 represents normal-weight concrete, while Figure 32 applies to semi-lightweight concrete. The two histograms are very similar in form and differ significantly only in mean value. Both histograms have the general form of a normal distribution, indicating that the variance is primarily due to experimental deviation. For normal-weight concrete at 3,000 psi strength, the average pull-out load is 11.5 kips, which corresponds

with the pull-out load for 3,000 psi concrete shown on Figure 16. For semi-lightweight concrete, the average pull-out load is 10.2 kips, which corresponds to the pull-out load for the 3,000 psi concrete shown on Figure 17.

The estimated standard deviation for the normal-weight concrete test distribution is 1.3, while the estimated standard deviation for the semi-lightweight concrete is 1.5. Since the variances of the two samples are nearly the same, it can be safely assumed, for the sake of tolerance interval estimates, that the population variability is known. Consider a lower-bound tolerance limit that is 2 kips below the mean value. Using the cumulative normal distribution with standard deviation of 1.4, it can be stated that at least 90% of all insert pull-out loads (4x4 samples) lie above these lower limits. (9.5 kips for normal weight and 8.2 kips for semi-lightweight concrete). Since the distribution is essentially normal, these tolerence limits are stated with almost 100% confidence.

6. DESIGN CONCLUSIONS

6.0 General

In establishing design conclusions, the various known paramenters affecting insert strength are first considered independently. This is a relatively definitive process based on previous discussions of experimental scatter, flexural tension effects, sustained load, and fatigue load. Combining all these effects together involves an engineering judgement process, and is therefore dependent on the individual structural engineer's design philosophy. Thus the final design recommendations should be considered as a suggested criteria for the particular set of circumstances described.

6.1 Aggregate and Insert Type

All three types of inserts can be considered similar for purposes of design load recommendations that encompass flexure, fatigue and sustained load effects.

The pull-out strength for the inserts is lower in specimens made with semi-lightweight concretes than in specimens made with the normal-weight concretes. This difference is

slightly less for fatigue loading than it is for static loads.

6.2 Concrete Strength

From Section 5.3, it is concluded that an increase in concrete compressive strength causes a predictable increase in insert pull-out strength. For a concrete strength range between 3,000 and 5,000 psi, and a concrete density range of 115 pcf to 145 pcf, the average static pull-out strength of the subject inserts in a reinforced concrete slab 4x4 specimens can be predicted by:

$$P_{4u}=2000+1.2W_c\sqrt{f_c'} \quad \text{- - - - - - - - - -} \quad 6.2(1)$$

where:

P_{4u}= 4x4 specimen pullout strength (lbs.)

W_c=density of concrete (pcf)

f_c'=concrete compressive strength (psi)

6.3 Concrete Flexural Tension Factor

Based on the assumption that the ultimate pull-out load of an insert will not stress the concrete slab to more than 90% of the slab's ultimate moment capacity, it is concluded that a reduction factor of $\phi_t=\overset{0.75}{\cancel{0.75}}$ should be used to account for the loss of insert strength due to flexural tension.

6.4 Reinforcement Quantity and Cover

From the discussions of Sections 5.4 and 5.5, it is concluded that the amount of reinforcing steel and its location affects the insert pull-out strength to a limited extent. The influence of steel depth is not significant for concrete cover up to 1-1/2 in. Figure 23 shows a 10% reduction in insert pull-out strength in going from 3/4 in. to 1-1/2 in. However, when it is recalled that this change in concrete cover reduces the slab moment capacity to the point where applied failure moment almost equals slab capacity moment, then it is apparent the 10% reduction in this strength is due primarily to the increased flexural tension cracking. Therefore, it has been taken into account by the flexural tension factor of Section 6.3.

The reinforcment spacing study of Section 5.5 shows that the #5 at 12 in. c/c should be the minimum reinforcing to which the design recommendations can be applied. As in the case of concrete cover, the loss of insert strength with bar spacing up to 12 in., is relatively small and fully accounted for by the flexural tension cracking factor of Section 6.3.

6.5 Sustained Load Factor

By referring to Section 5.6 and Figure 24, it is shown that a sustained insert load 90% of the static pull-out load can result in failure. Thus, if sustained load is to be considered as a prime parameter, a reasonable reduction factor ($\emptyset_s$) would be 0.85. Since it is physically impossible to develop maximum sustained load and maximum fatigue load simultaneously, the maximum effects of sustained load and fatigue load are not cumulative. Since sustained load is not as detrimental to the insert behavior as is fatigue load, it may be unnecessary to consider this parameter, provided fatigue loading has been considered.

6.6 Fatigue Load Factor

For inserts subjected to cyclic loads, such as those applied by vibrating mechanical equipment, a fatigue load reduction factor should be considered. Based on the results discussed in Section 5.7, the semi-lightweight concrete should have a fatigue reduction factor ($\emptyset_{fs}$) of 0.70. The normal-weight concrete should be associated with a 0.65 fatigue reduction factor ($\emptyset_{fh}$). It should be noted that fatigue tests

were performed on 10 ft. long concrete slabs, which means that these factors have incorporated in them a reduction due to flexural tension cracking. It is also important to recognize that the probability of getting a fatigue load and a sustained load large enough to adversely affect the insert strength in a cumulative fashion is extremely small.

6.7 <u>Experimental Scatter Factor</u>

Based on the discussion of Section 5.9, it is apparent that most insert test loads are within 2 kips of the mean. Since the averages for the two distributions (semi-lightweight and normal concrete) are 10.2 kips and 11.5 kips, a suitable reduction factor to account for experimental scatter should be in the order of 20% of the mean. This suggests an experimental scatter factor (ϕ_e) of 0.80.

7.0 Design Criteria

7.1 <u>Design Recommendations</u>

7.1.1 Design Safety Factor

In Sections 6.3 through 6.7 four reduction factors were

defined. These are summarized as follows:

Experimental Deviation Factor, $\emptyset_e=0.80$

Fatigue Reduction Factors, $\emptyset_{fh}=0.65$

$\emptyset_{fs}=0.70$

Flexural Tension Factor, $\emptyset_t=0.75$

Sustained Load Factor, $\emptyset_s=0.85$

Since fatigue tests were performed on long slabs, the fatigue factors include a flexural tension effect. Thus the two most severe combinations of reduction factors are:

$$\emptyset_f=\emptyset_e \times \emptyset_{fh}=0.52$$

$$\emptyset_{ts}=\emptyset_e \times \emptyset_t \times \emptyset_s=0.51$$

In accordance with standard engineering practice, it is necessary to select a design safety factor to account for unpredictable situations, such as quality control deviation or an undetected structural overload. In the case of live loads, one commonly used load factor is 1/1.8=0.56 (See ACI 318-63). If this factor is combined with the more conservative of the reduction factors then the total reduction factor ($\emptyset$) is 0.29, giving a maximum safety factor of 3.5.

7.1.2 Design equations

The recommended design equation for the allowable load on an insert is:

$$P = \phi\ (2000+1.2W_c\sqrt{f_c'})\ - - - -\ 6.8(1)$$

For ϕ =0.29, this becomes:

$$P = 580+0.35W_c\sqrt{f_c'}\ - - - - - - -\ 6.8(2)$$

Where P=allowable design load per insert (lbs.),

W_c=density of concrete (lbs/cu. ft.)

f_c'=compressive strength of concrete

Some typical values of P have been tabulated in Table 12. See Figures 16 and 17 for a graphical representation of the design equations.

7.2 Design Limitations

7.2.1 Connecting Hardware

As for most types of design recommendations their proper utilization depends to a certain extent on the use of good engineering judgement. In this case the recommendations are

for inserts, similar to those tested, embedded in properly placed reinforced concrete slabs. As has been previously noted the critical factor in the insert suspension system may not be the pull-out strength of the insert but the properties of the connecting hardware. Specifically, the threaded rods.

Under certain conditions the properties of the threaded bolt may be extremely critical. Such a condition might occur when an auxilary suspension member is bolted to the ceiling in such a manner that there is an initial-tension in the bolt; tension over and above that caused by the suspended load.

Thus it is apparent that allowable design insert loads as computed from the equation of Section 7.1.2 and as presented in Table 12 should be used only for moderate fatigue or static loading conditions unless the fatigue properties of the connecting hardware are fully considered.

7.2.2 Insert Spacing

If and when it is desirable to have inserts spaced closer than 3 ft. on centers the allowable load on each insert should be reduced. In light of the absence of data on this factor it would seem advisable to limit insert loading

so that the total design load on the inserts within any 3 ft. diameter area is that allowable on a single insert.

This factor needs researched because there could be situations where it would be advantageous to group a number of inserts fairly close together.

7.2.3 Inserts Other Than Those Tested

It is recommended that inserts, different from those tested, be evaluated using the 4x4 reinforced slabs and the static test procedures described heretofore.

7.2.4 Inserts in Lightweight Aggregate Concretes

When designing slabs to be made from either lightweight or semi-lightweight concretes the allowable insert load may be less than the 3000 lbs. normally used by the Post Office Department.

If this 3000 lb. insert load is considered to be the lower limit the design compressive strength for the lightweight aggregate concrete may have to be increased. This increase would pose no problem for most of the aggregates produced at the present time.

An alternate to this increase in the concrete strength would be to require an increase in the unit weight of the concrete.

7.2.5 Installation of Inserts

During this investigation a number of inserts were "lost" while placing the concrete. This can easily happen in the construction of an actual structure since the method of holding the insert is not accident-proof. The concrete handlers should be warned to keep their tools and vibrator spuds away from the inserts.

In the laboratory good results were obtained by assigning one man to be fully responsible for the inserts and for placing the concrete around the inserts.

If the loss of inserts is a major problem in the field it may be necessary to design a better method of holding the inserts while placing the concrete.

In the advent of a missing insert some type of a drilled-in anchoring device would have to be installed. The design recommendations for inserts in this report do not apply to these other types of anchors.

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TABLE 1

TYPICAL MANUFACTURER'S CATALOG DATA FOR 3/4-INCH INSERTS

Insert	Catalog Name	Type of Metal	Overall Length	Manufacturers Ultimate Strength In Concrete	Manufacturers Working Load
			In.	Lbs.	Lbs.
A	Universal-All size nut	Malleable Iron	3-5/16	—	3,000
B	Concrete Insert	Zinc Casting Alloy	3	12,500	—
C	Do	Do	1-11/16	6,900	3,000
D	Malleable Adjustable	Malleable Iron	2-1/2	7,650	3,020
E	Threaded Insert	Steel	3-3/8	10,000	—
F	Do	Gray Cast Iron	3-1/4	12,500	3,100
G	Do	Malleable Iron	3-1/4	15,300	3,800
H	Rocket	Do	3-5/8	11,900	3,020
I	Kohler	Gray Cast Iron	3	12,400	3,020
J	Thin Slab Ferrule	Steel	1-5/8	—	—
K	Mitey-Mite	Malleable Iron	1-1/2	6,600	2,500

Note: Inserts recommended as suitable for use with 4 1/2 in. thick concrete slabs.

TABLE 2

AGGREGATE DESCRIPTIONS

Aggregate Designation	Max. Size in.	Type of Aggregate Coarse	Type of Aggregate Fines	Source of Aggregate Coarse	Source of Aggregate Fines
H-1	3/4	Crushed Stone	Natural Sand	Md.	Md.
H-2	3/4	Gravel	Natural Sand	Md.	Md.
L-1	3/4	Expanded Shale	Natural Sand	Va.	Md.
L-2	3/4	Expanded Shale	Natural Sand	Ga.	Md.
L-3	3/8	Expanded Shale	Natural Sand	Ill.	Md.
L-4	1/2	Expanded Shale	Expanded Shale	Calif.	Calif.
L-5	3/4	Expanded Shale	Natural Sand	Texas	Md.

Note: The expanded shale lightweight aggregates were furnished through the courtesy of the Expanded Shale, Clay and Slate Institute, Washington, D.C. Although these lightweight aggregates are identified as being expanded shales, the actual raw materials could be either shale, clay or slate.

TABLE 3

CONCRETE MIXES MADE WITH NORMAL WEIGHT AGGREGATES

Concrete	Nominal Cement Content	Nominal 28-Day Compressive Strength	Measured Slump
	Sacks/Yd^3	psi	in.
H-1	5	2500	--
H-2	5	2500	4
H-1A	6	3000	5
H-2A	6	3000	5
S-1	5	2500	6
S-2	5	2500	6 1/2
S-3	5	2500	5
S-4	4	2000	7
W-1	5	2500	5
F-1	5	2500	2 1/2
F-3	5	2500	--
F-4	5	2500	6
C-1	5	2500	5 1/2
C-3	5	2500	5
X-1A	5	2500	4 1/2
X-1B	4 1/2	2000	5 1/2
X-2A	5	2500	4 1/2
X-2B	5	2500	4 1/2
X-3A	4 1/2	2000	6
X-3B	7	3500	3 and 6
X-4A	4 1/2	2000	6
X-20A	5	2500	5
X-20B	5	2500	6
X-20C	5	2500	4

Note: All normal weight concretes were made with the H-1 crushed stone coarse aggregate except for concretes H-2 and H-2A which were made with the H-2 gravel.

TABLE 4

NORMAL WEIGHT CONCRETE STRENGTHS

Concrete	Compressive Strength	Splitting Strength	Age At Test
	PSI	PSI	Days
H-1	3480	---	7
H-2	3150	380	7
H-1A	3950	---	27
H-2A	4110	450	19
S-1	3830	---	21
S-2	3940	---	15
S-2	3110	---	12
S-4	2640	---	18
W-1	3330	420	7
F-1	5280	510	10
F-3	3830	340	13
F-4	3500	420	13
C-1	3630	---	34
C-3	5010	440	40
X-1A	4560	460	23
X-1B	2990	368	20
X-2A	4560	445	24
X-2B	3670	338	28
X-3A	3180	340	7
X-3B	5570	434	14
X-4A	3440	334	20
X-20A	4090	320	10
X-20B	3100	320	9
X-20C	3200	312	7

TABLE 5

CONCRETE MIXES MADE WITH LIGHTWEIGHT AGGREGATES

Concrete	Aggregate	Nominal Cement Content	Nominal 28-Days Compressive Strength	Measured Slump	Fresh Unit Weight
		Sacks/Yd^3	Psi	In.	Pcf
L-1	L-1	6	3000	6 1/2	117
L-2	L-2	5 3/4	3000	1 3/4	114
L-3	L-3	5 1/2	3000	1	115
L-4	L-4	5 1/4	3000	1 1/2	96
L-5	L-5	5 1/2	3000	2	120
L-1A	L-1	8	5000	2 1/2	119
L-2A	L-2	7	5000	3	117
C-2	L-1	6	3000	2	119
C-4	L-1	6	3000	8 1/2	118
F-2	L-1	6	3000	3 1/2	120
X-2C	L-1	6	3000	4"	121
X-2D	L-1	6	3000	3	119

Note: All concretes were semi-lightweight (sanded) except for L-4 which was lightweight.

TABLE 6

LIGHTWEIGHT AGGREGATE CONCRETE STRENGTHS

Concrete	Compressive Strength Psi	Splitting Strength Psi	Age At Test Days
L-1	2640	270	35
L-2	3040	350	8
L-3	5420	400	17
L-4	3300	280	5
L-5	3370	330	8
L-1A	5050	370	19
L-2A	5200	480	20
C-2	2800	---	31
C-4	2350	230	42
F-2	3450	---	11
X-2C	4200	440	31
X-2D	3810	360	35

TABLE 7

TESTS FOR AGGREGATE AND INSERT VARIATION

Test Set No.	Concrete fc'	Average Load*, Kips		
		Type 1	Type 2	Type 3
H-1	3480	12.0	10.0	12.0
H-2	3150	15.8	12.5	14.6
H-1A	3950	16.2	14.9	17.4
H-2A	4110	14.5	13.5	13.1
L-1	2640	11.6	10.2	11.5
L-2	3040	9.9	8.0	8.9
L-3	5420	11.5	10.9	10.3
L-4	3300	9.3	7.2	7.3
L-5	3370	11.5	9.2	10.6
L-1A	5050	15.8	15.3	14.1
L-2A	5200	13.4	11.8	11.5

*Average of 4 Insert Pull-Out Tests.

TABLE 8

ELEMENTARY STATISTICS FOR CONCRETE AND INSERT TYPE

Insert Type	Concrete Type	Sample Mean	Range (kips)	No. Samples
1	Normal	14.6	7.3	16
2	Normal	12.7	6.8	16
3	Normal	14.3	8.3	16
1	Semi-Light	12.3	7.9	24
2	Semi-Light	10.9	7.6	24
3	Semi-Light	11.2	6.8	24
All	Normal	14.0	8.3	48
All	Semi-Light	11.5	9.3	72
1	All	13.2	8.1	40
2	All	11.6	8.9	40
3	All	12.4	9.9	40

TABLE 9

EFFECT OF REINFORCEMENT COVER AND SPACING

Test No.	Re-bar Spacing (ins)	Re-bar Cover (ins)	Pull-Out Load (kips)	Average (kips)	Range (kips)
X1B-1	#5x12	3/4	10.3		
X1B-2	#5x12	3/4	9.9	10.1	0.4
X1B-3	#5x12	3/4	10.0		
X1B-4	#5x12	1 1/2	9.0		
X1B-5	#5x12	1 1/2	9.0	9.1	0.2
X1B-6	#5x12	1 1/2	9.2		
X1B-7	#5x12	3	7.1		
X1B-8	#5x12	3	6.8	7.0	0.4
X1B-9	#5x12	3	7.0		
X1B-10	#5x6	3/4	10.4		
X1B-11	#5x6	3/4	10.9	10.7	0.5
X1B-12	#5x6	3/4	10.9		
X1A-1	#4x3 1/2	3/4	13.8		
X1A-2	#4x3 1/2	3/4	14.3	14.7	2.2
X1A-3	#4x3 1/2	3/4	16.0		
X1A-4	#5x6	3/4	13.6		
X1A-5	#5x6	3/4	13.7	13.8	0.4
X1A-6	#5x6	3/4	14.0		
X1A-7	2-#5x12	3/4	13.5		
X1A-8	2-#5x12	3/4	13.9	14.3	1.9
X1A-9	2-#5x12	3/4	15.4		
X1A-10	#4x12	2	9.9		
X1A-11	#4x12	2	10.4	9.9	1.0
X1A-12	#4x12	2	9.4		

NOTES

1. Concrete Type X1A was normal weight with $f_c' = 4560$ psi.

2. Concrete Type X1B was normal weight with $f_c' = 2990$ psi.

TABLE 10

COMPARISON OF THEORETICAL AND TEST RESULTS
4x4 SPECIMENS

	Nominal Strength of Concrete	Pull-Out Load (P_u4) by Concrete Type		
		Normal-Weight (W_c=142 pcf)	Semi-Light-Weight (W_c=118 pcf)	Lightweight (W_c=96 pcf)
	psi	kip	kip	kip
Theoretical*	3000	11.4	9.8	8.3
Test**	3000	11.5	10.2	8.1
Theoretical*	5000	14.0	12.0	10.1
Test**	5000	14.3	12.3	----

*Theoretical: $P_u4 = 2.0 + .0012\ W_c \sqrt{f'c}$ (kips).

**Test results are the average of all samples within the range of the nominal concrete strength.

TABLE 11

Effect of Angular Pull on Insert Pull-Out Load*

Test No.	Load Angle**	Insert Angle**	Pull-Out Load Individual	Pull-Out Load Average
	degree	degree	kip	
X4A-1	90	90	11.8	
-2	90	90	12.0	11.8
-3	90	90	11.7	
-4	90	90	11.7	
-5	70	90	12.4	
-6	70	90	12.2	12.4
-7	70	90	12.6	
-8	70	90	12.4	
-9	90	70	13.1	
-10	90	70	13.7	13.4
-11	90	70	13.2	
-12	70	70	13.8	13.8

*Concrete Strength, $f_c' = 3440$ psi.

**Measured from plane of slab.

TABLE 12

ALLOWABLE DESIGN LOADS

Concrete Strength, f'_c	Design Loads	
	Normal-Weight Concrete	Semi-Lightweight Concrete
psi	lb	lb
3000	3300	2800
4000	3700	3200
5000	4100	3500

Notes:

1. Design loads computed for inserts embedded in concrete with unit weights of 142 pcf for the normal-weight and 117 pcf for the semi-lightweight concrete.

2. Semi-Lightweight Concrete with lightweight coarse aggregates and normal sand fine aggregate.

3. These are allowable design loads for only the inserts when embedded in 4 1/2 in. thick reinforced slabs made with the specified concrete. The effect of the fatigue loading on the connecting hardware must also be considered. In general the maximum allowable load on an insert may be fully controlled by the allowable load on the connecting hardware when cyclic loading is expected.

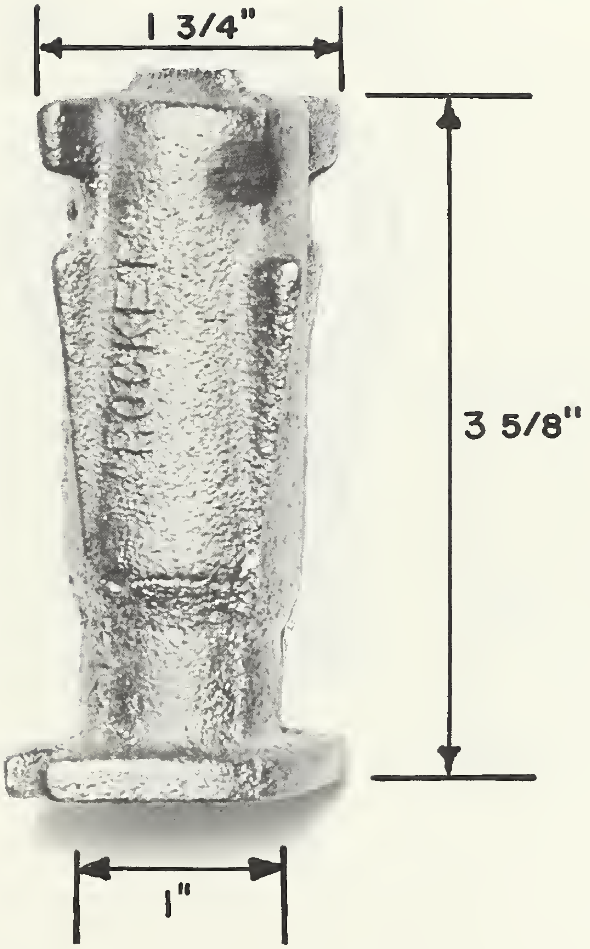

Fig. 1 Type 1 Insert.

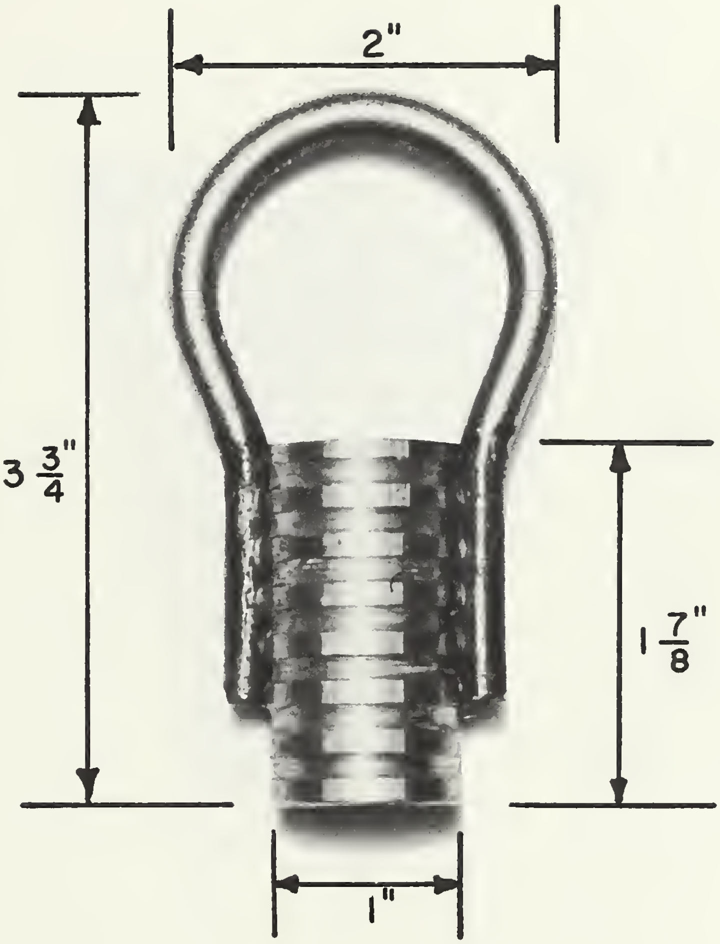

Fig. 2 Type 2 Insert.

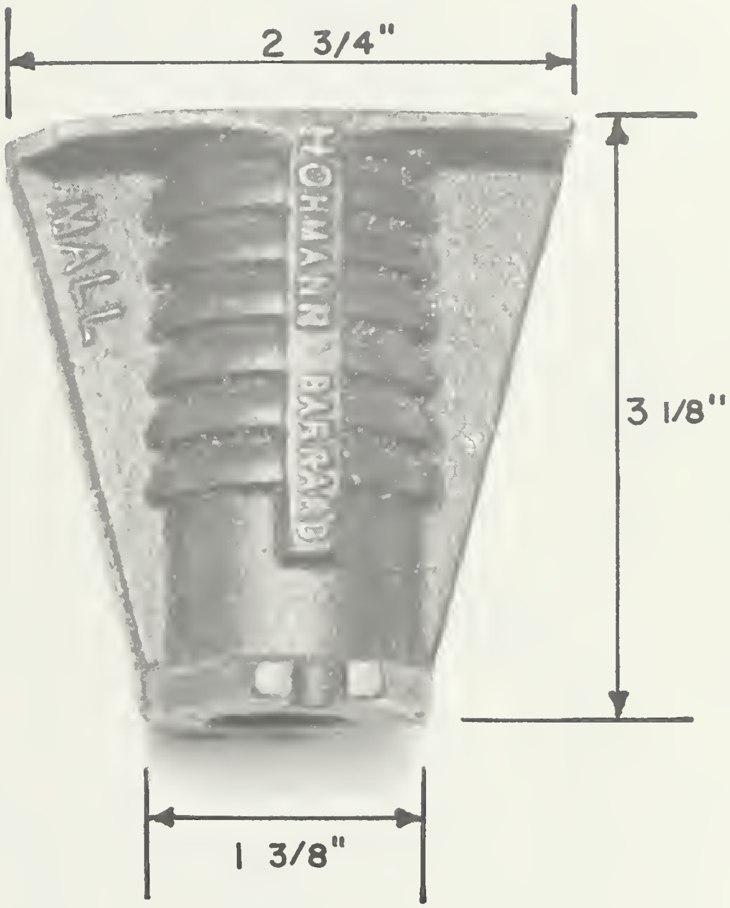

Fig. 3 Type 3 Insert.

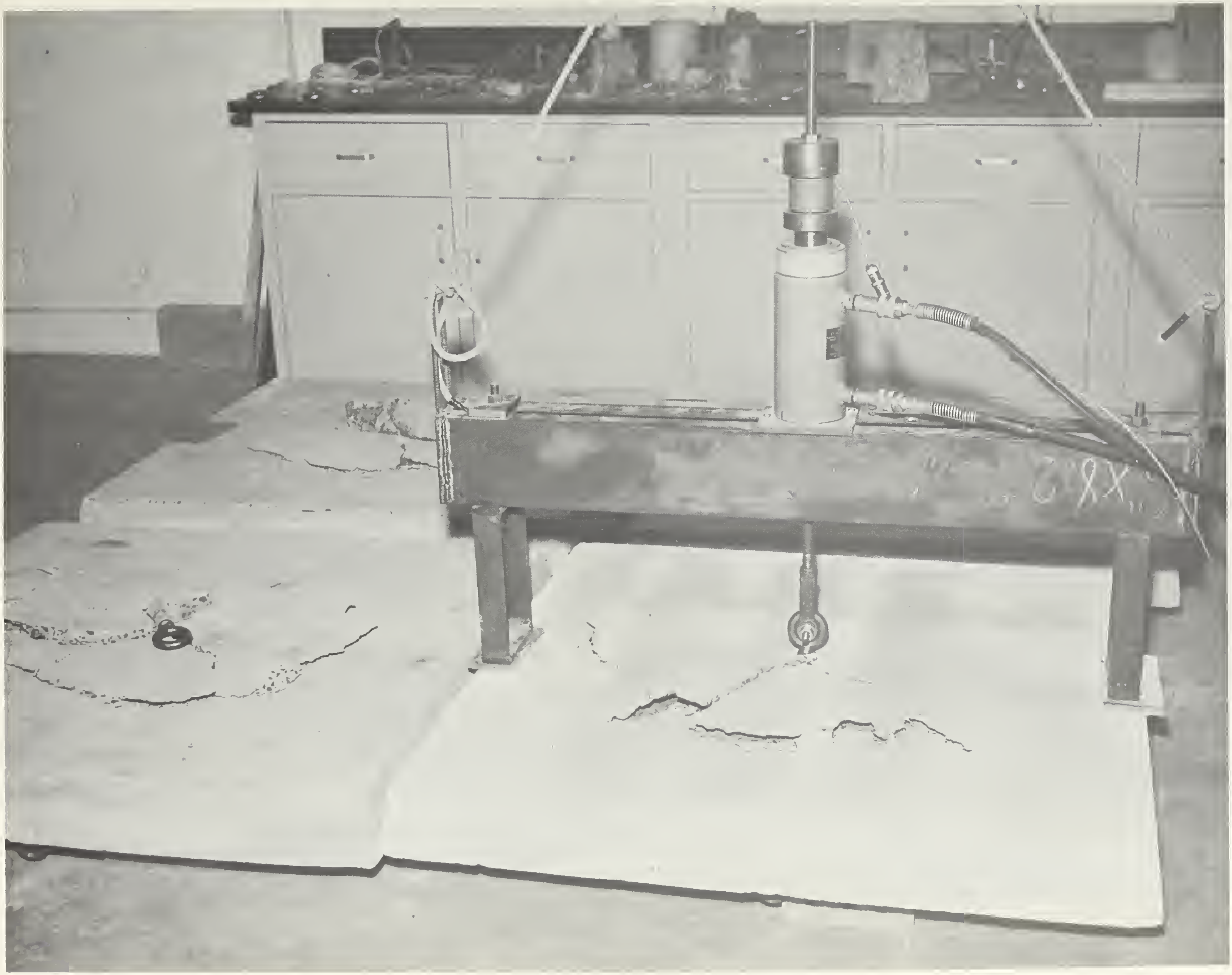

Fig. 4 Static Test on 4 x 4 Specimen.

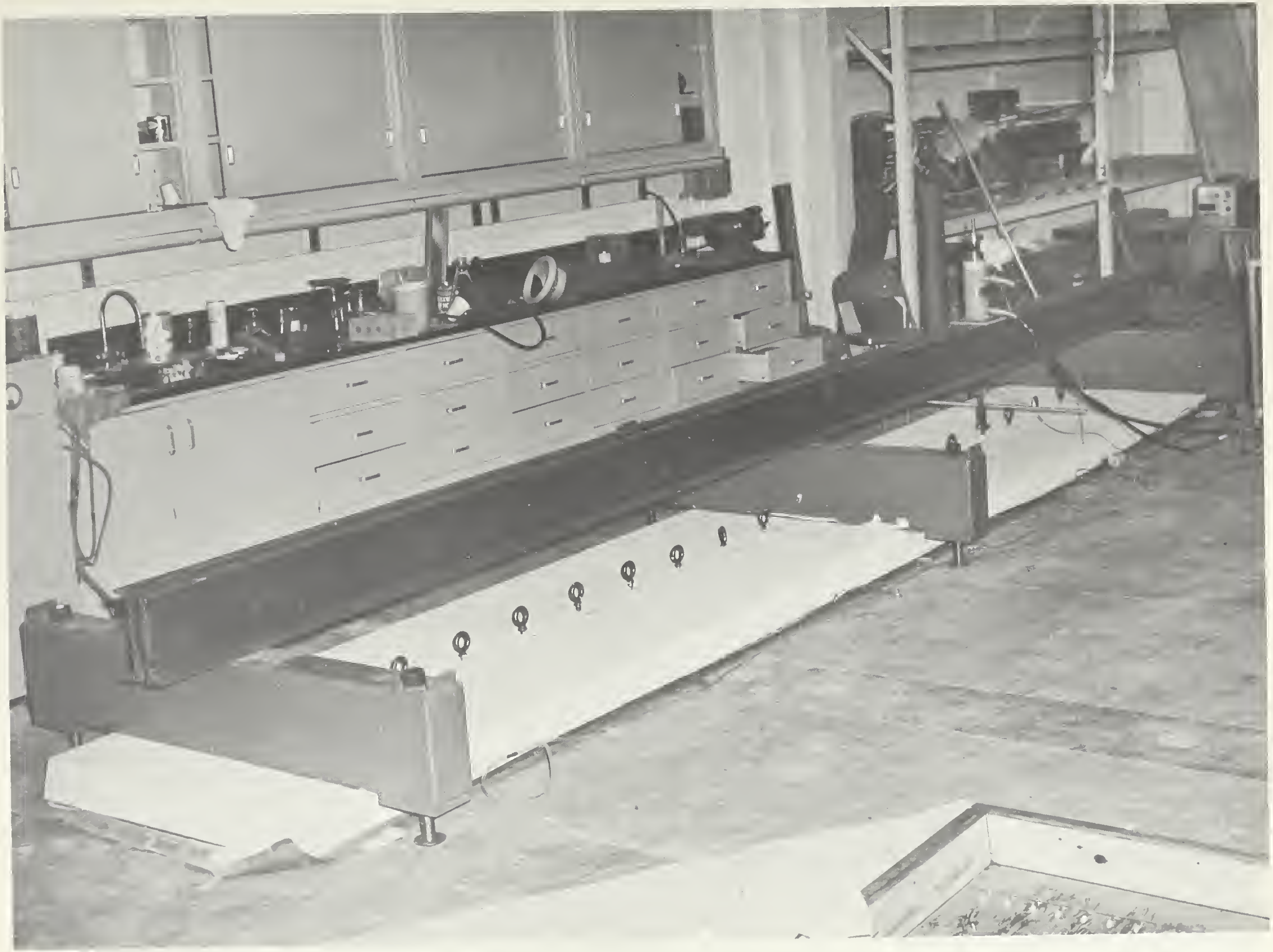

Fig. 5 Static Test on 4 x 22 Specimen.

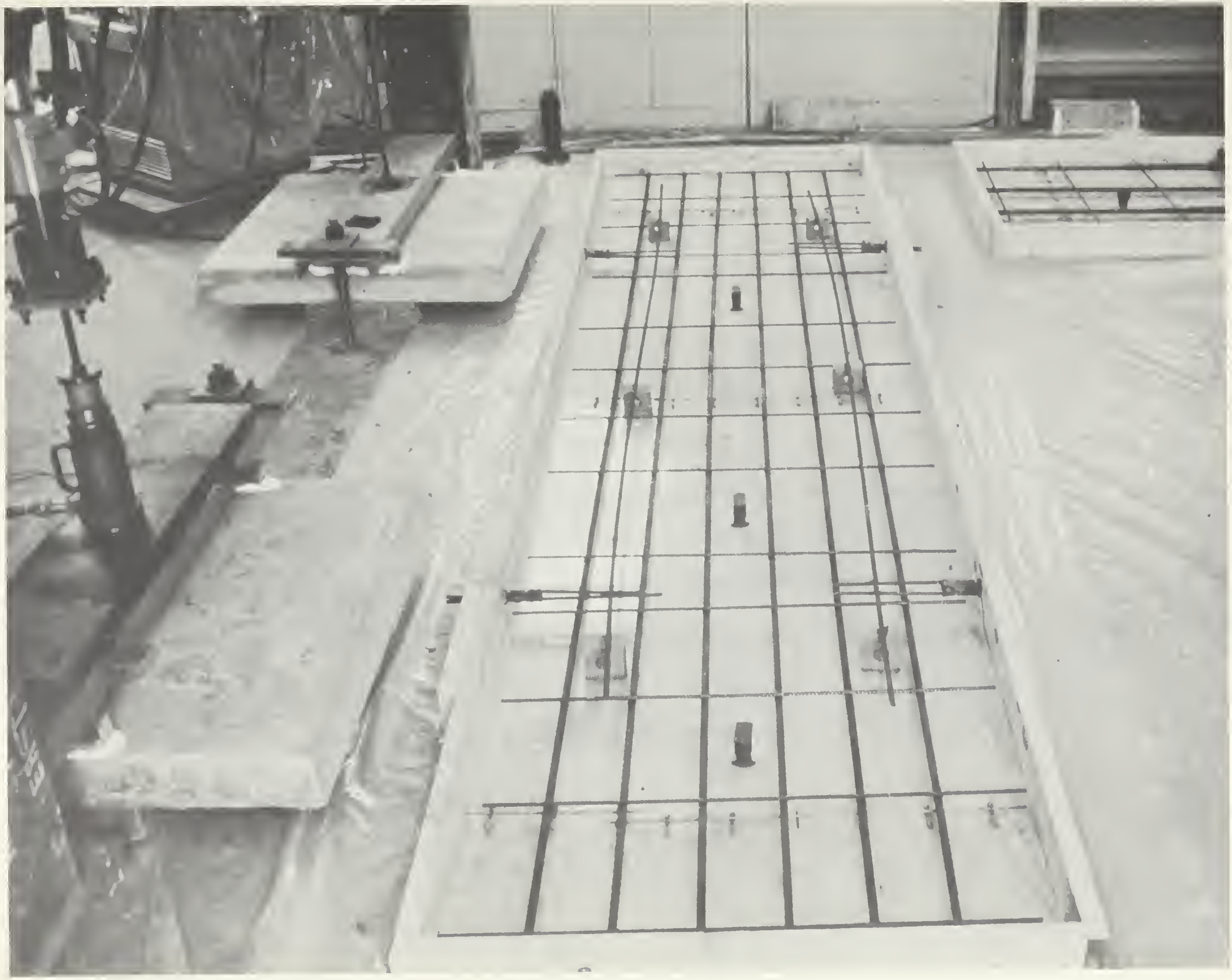

Fig. 6 Fabrication of 4 x 16 Specimens.

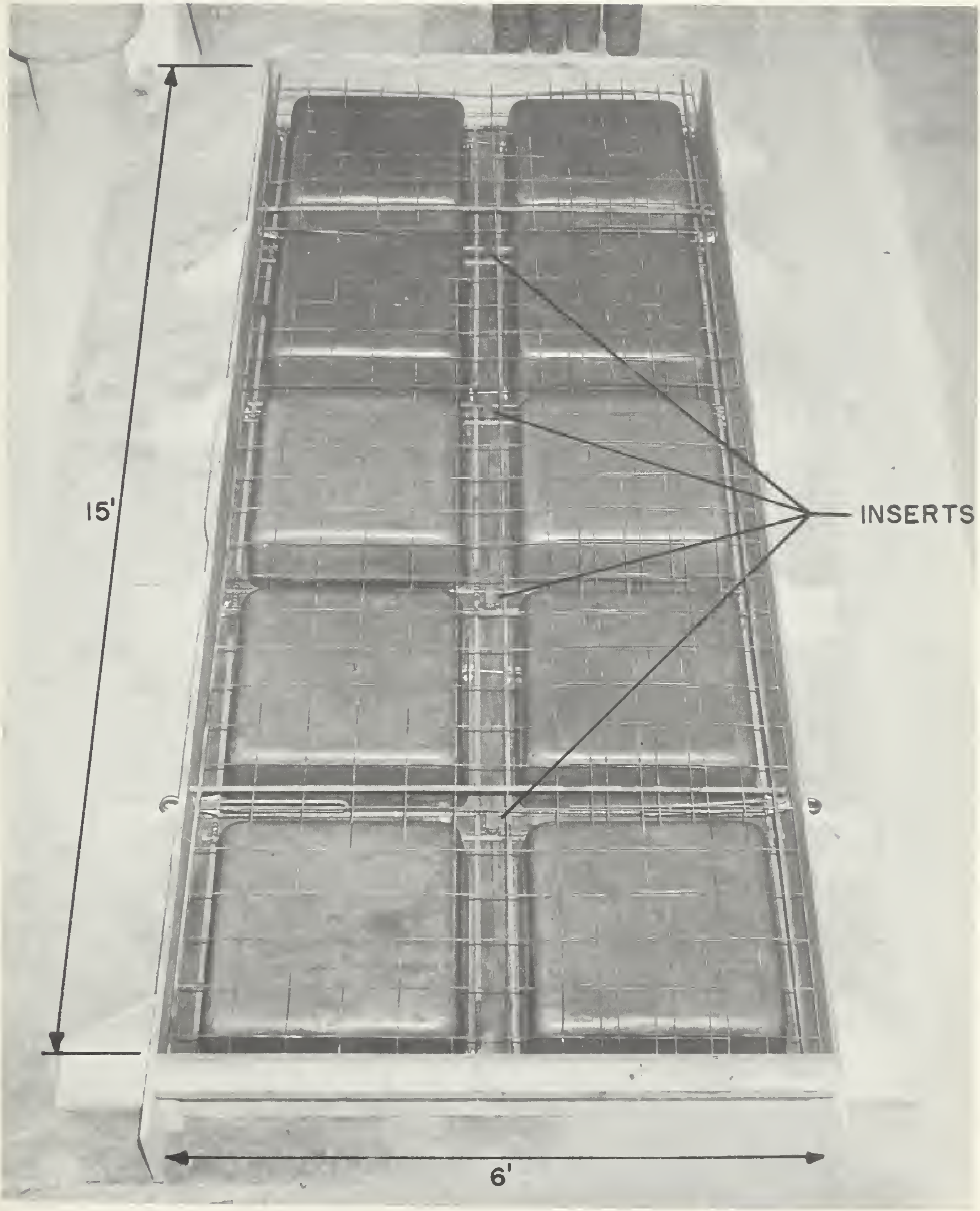

Fig. 7 Fabrication of Waffle Slab Specimen

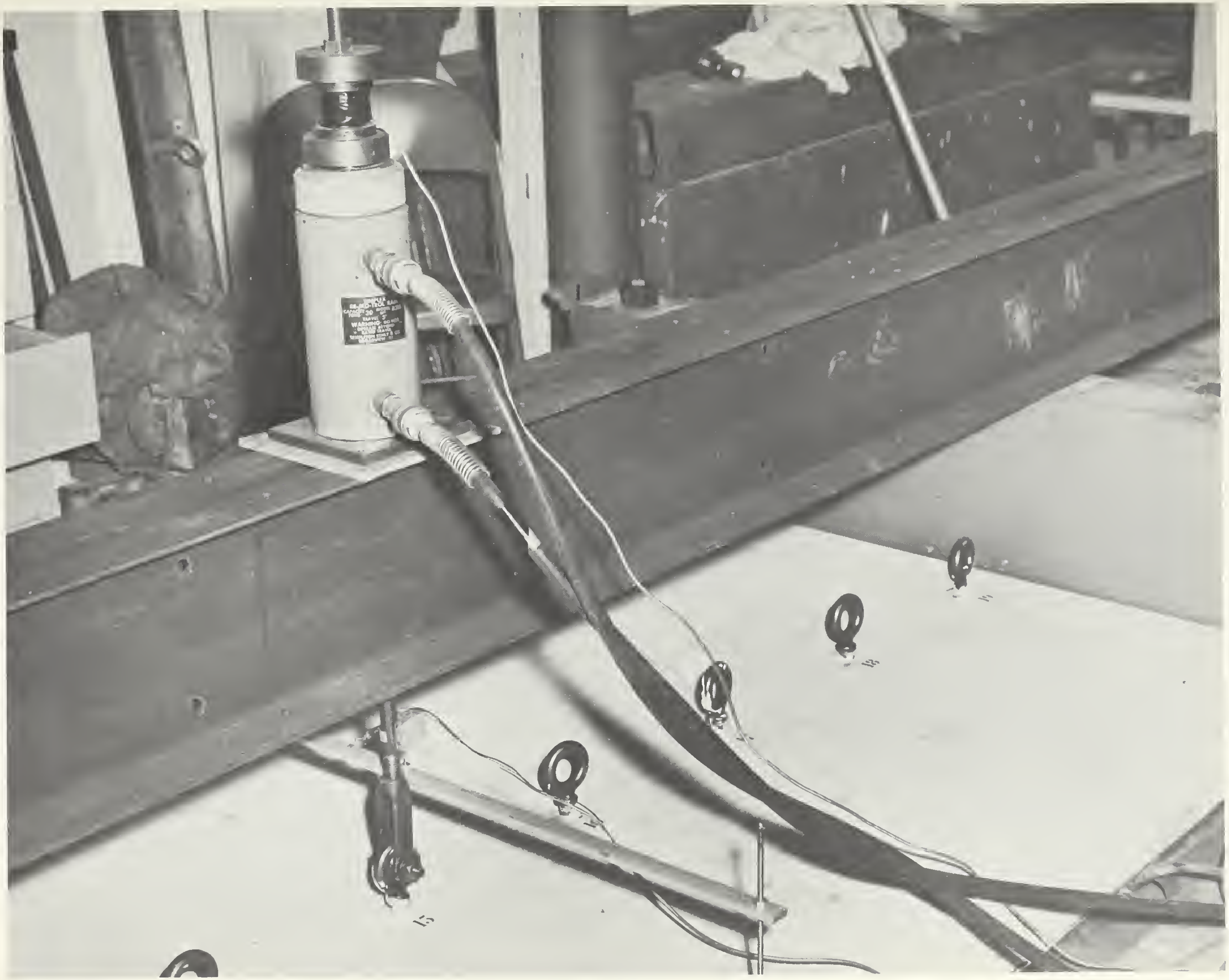

Fig. 8 Close-up of Static Test on 4 x 22 Specimen.

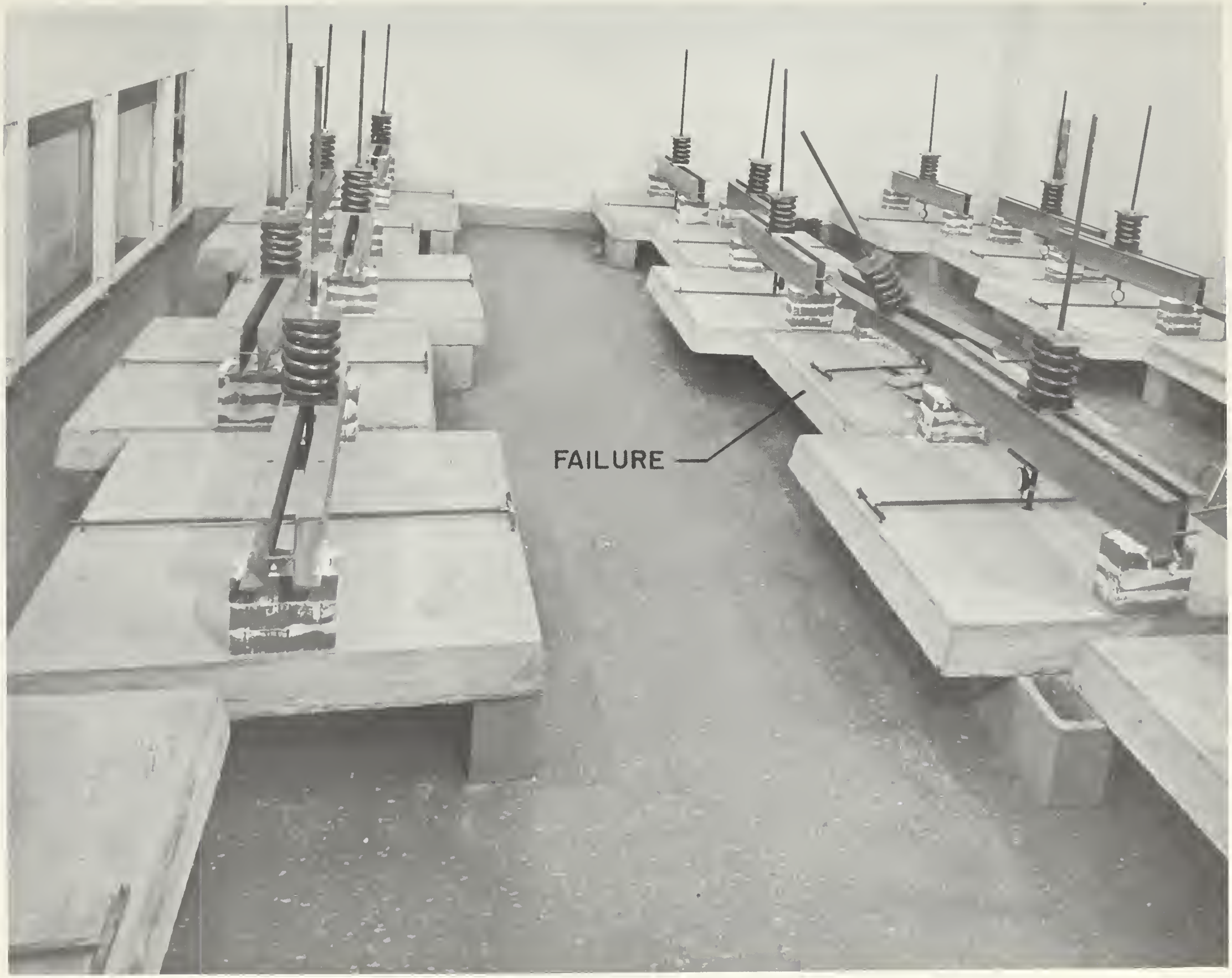

Fig. 9 Sustained Load Tests on 4 x 4 Specimen.

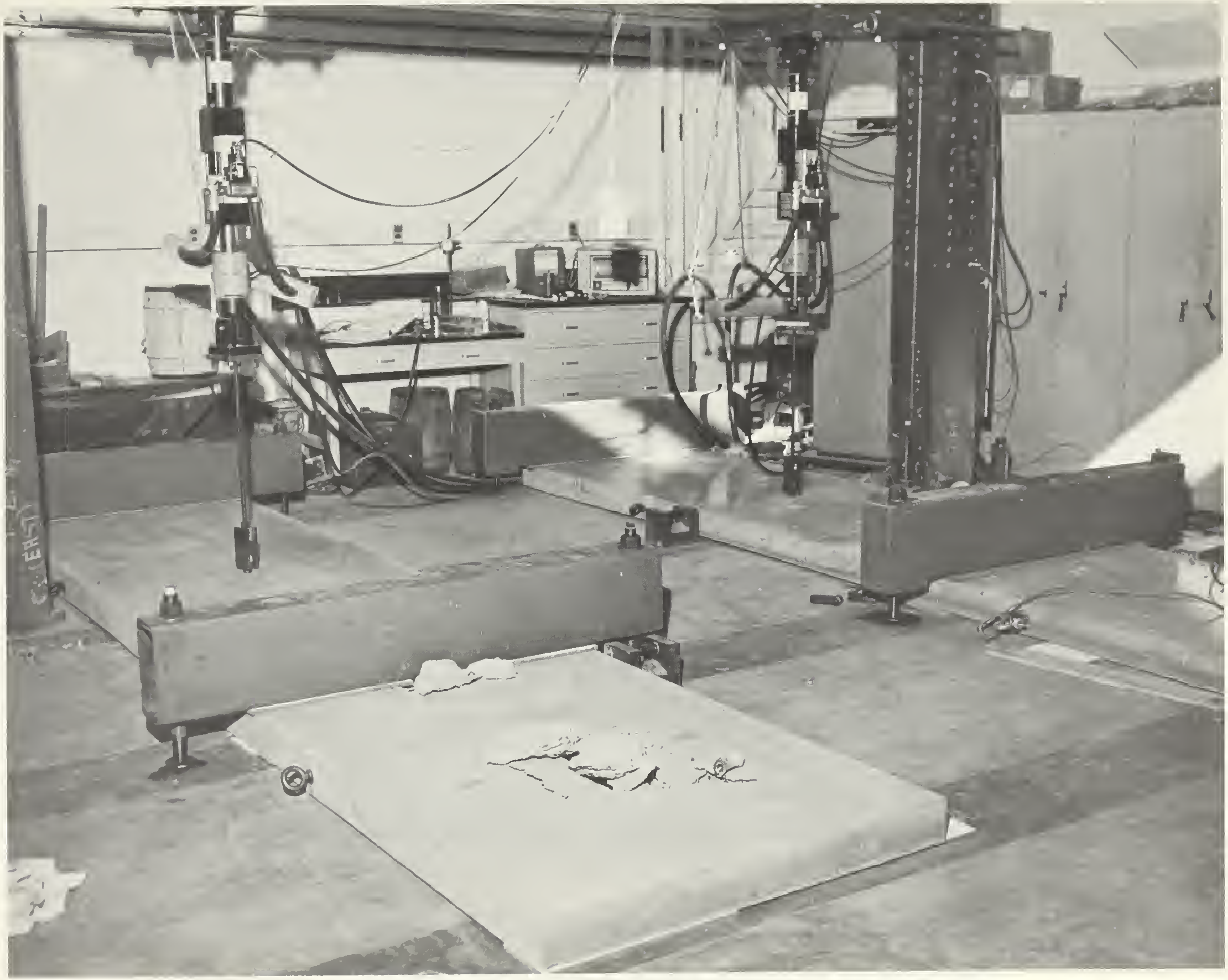

Fig. 10 Fatigue Tests on 4 x 16 Specimen.

Fig. 11 - Typical Load - Movement Data for Static Pull-Out Test

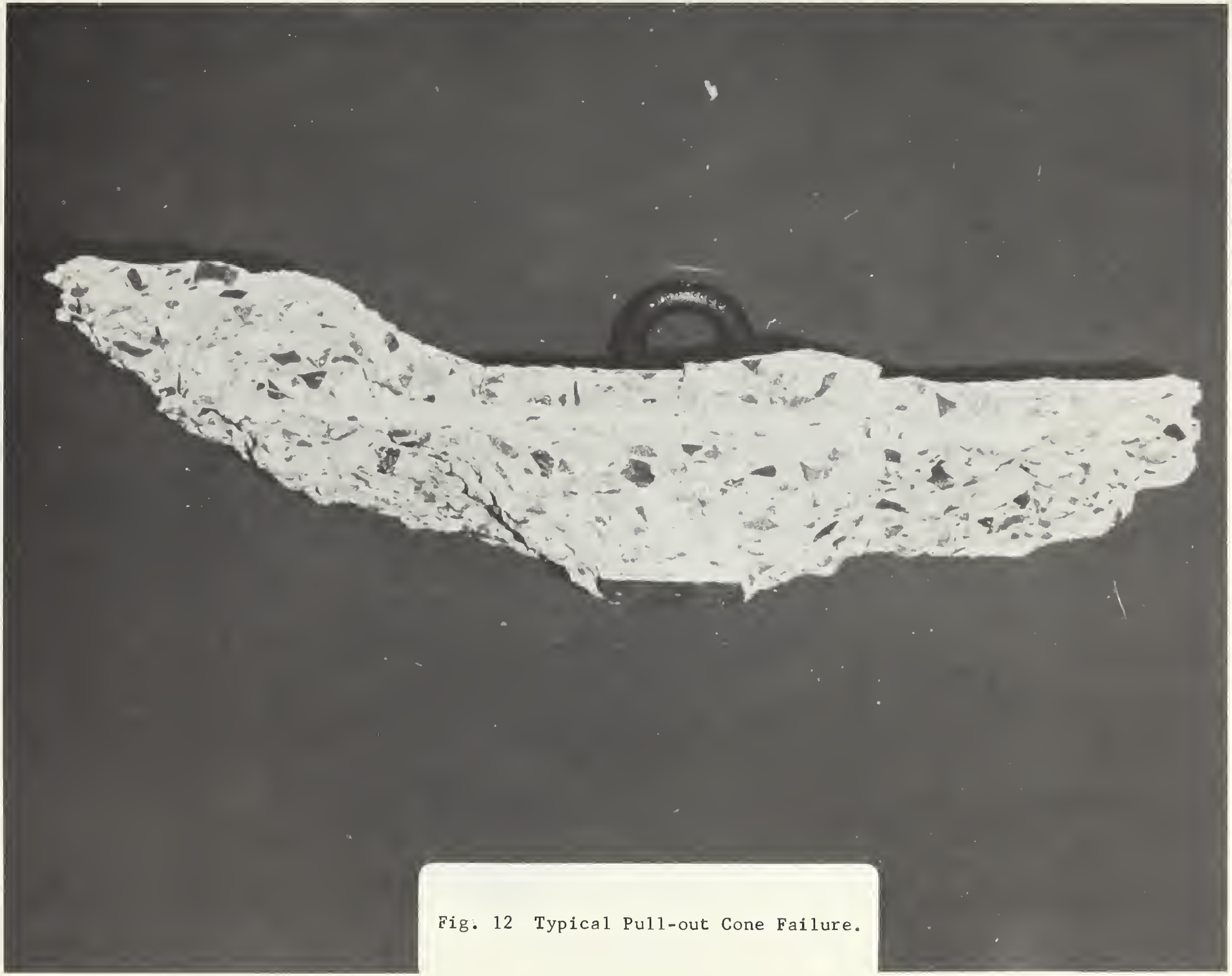

Fig. 12 Typical Pull-out Cone Failure.

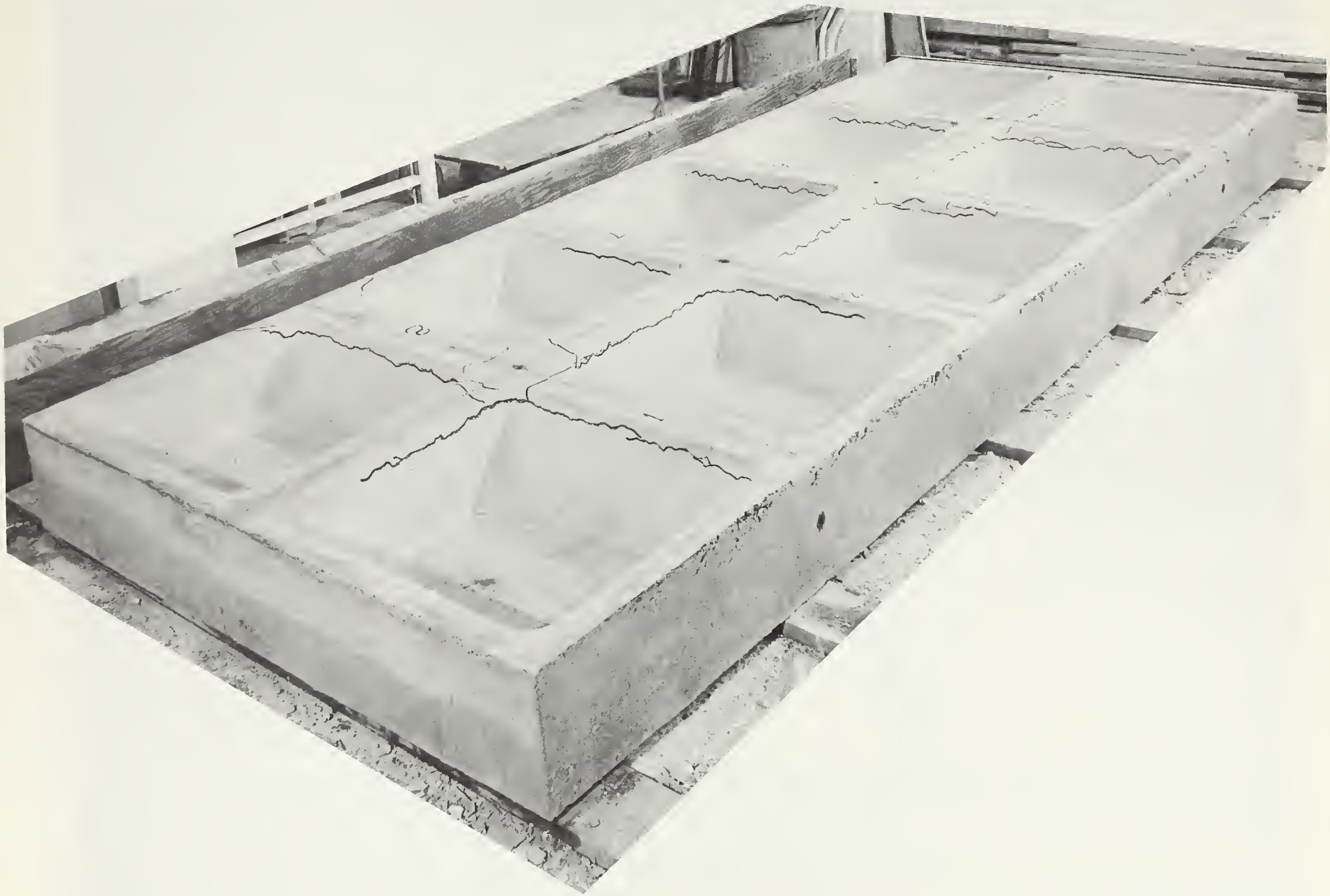

Figure ~~8~~ 13. Waffle Slab after Testing

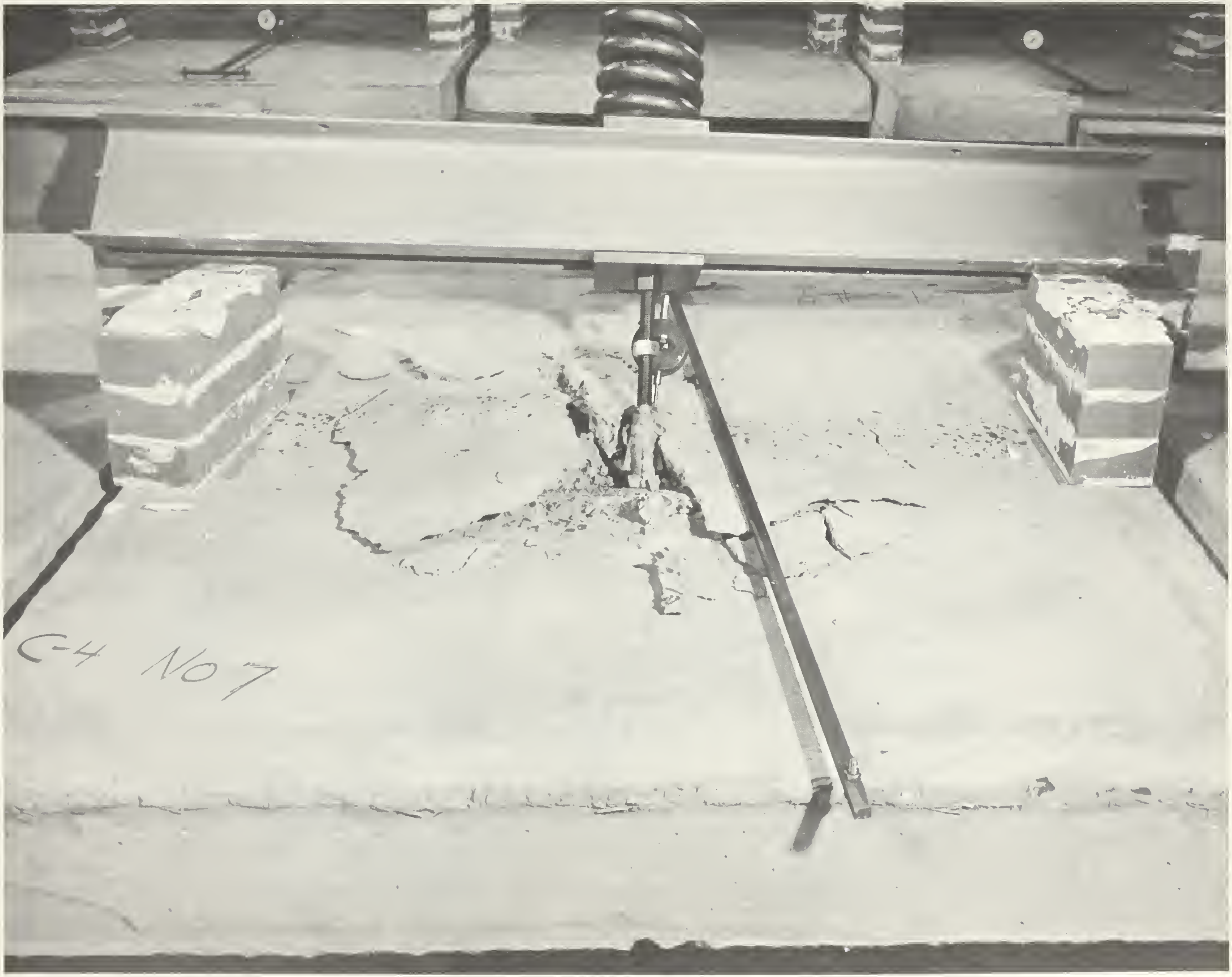

Fig. 14 Sustained Load Failure on 4 x 4 Specimen.

FLOW CHART

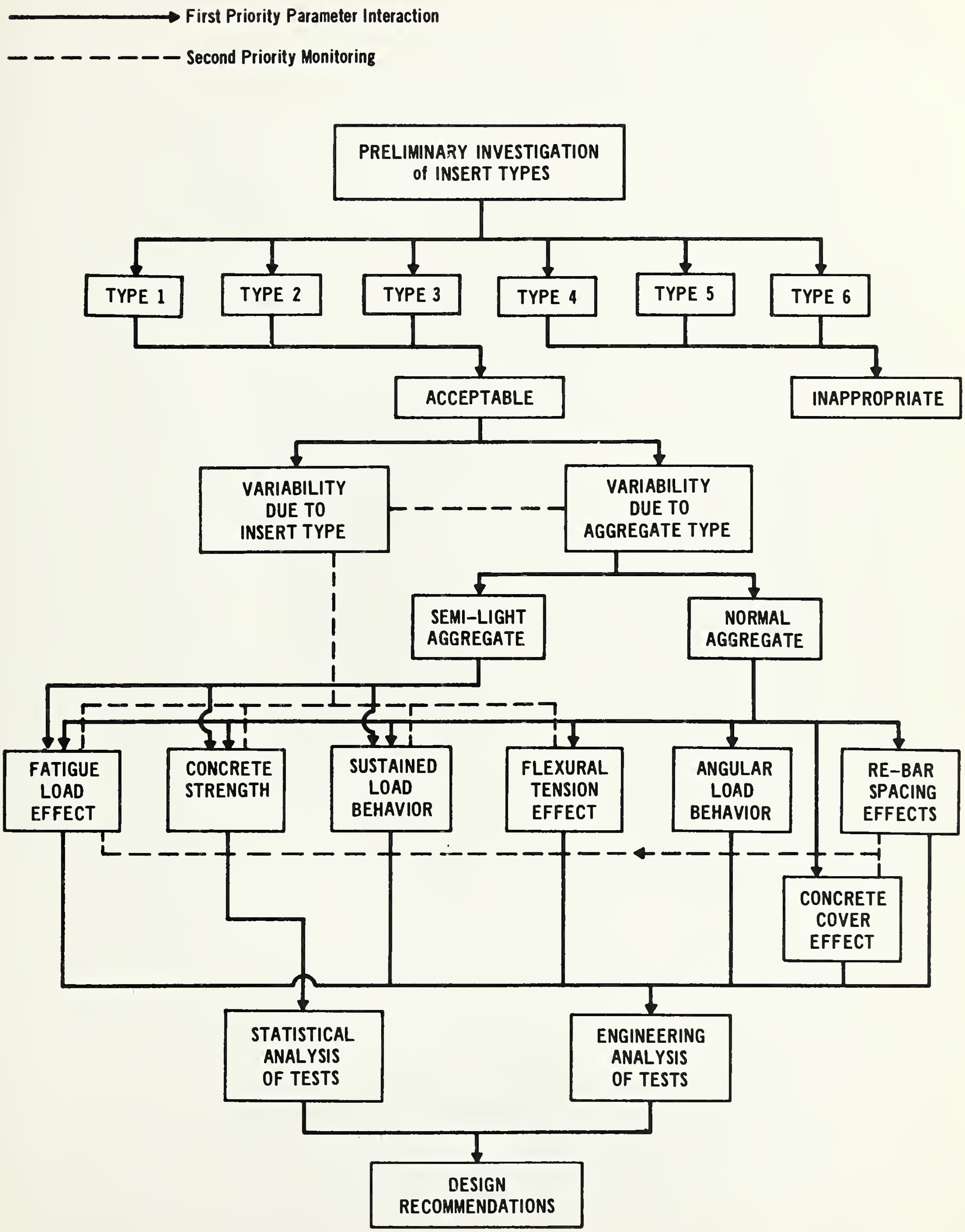

Figure 15 - Project Flow Chart

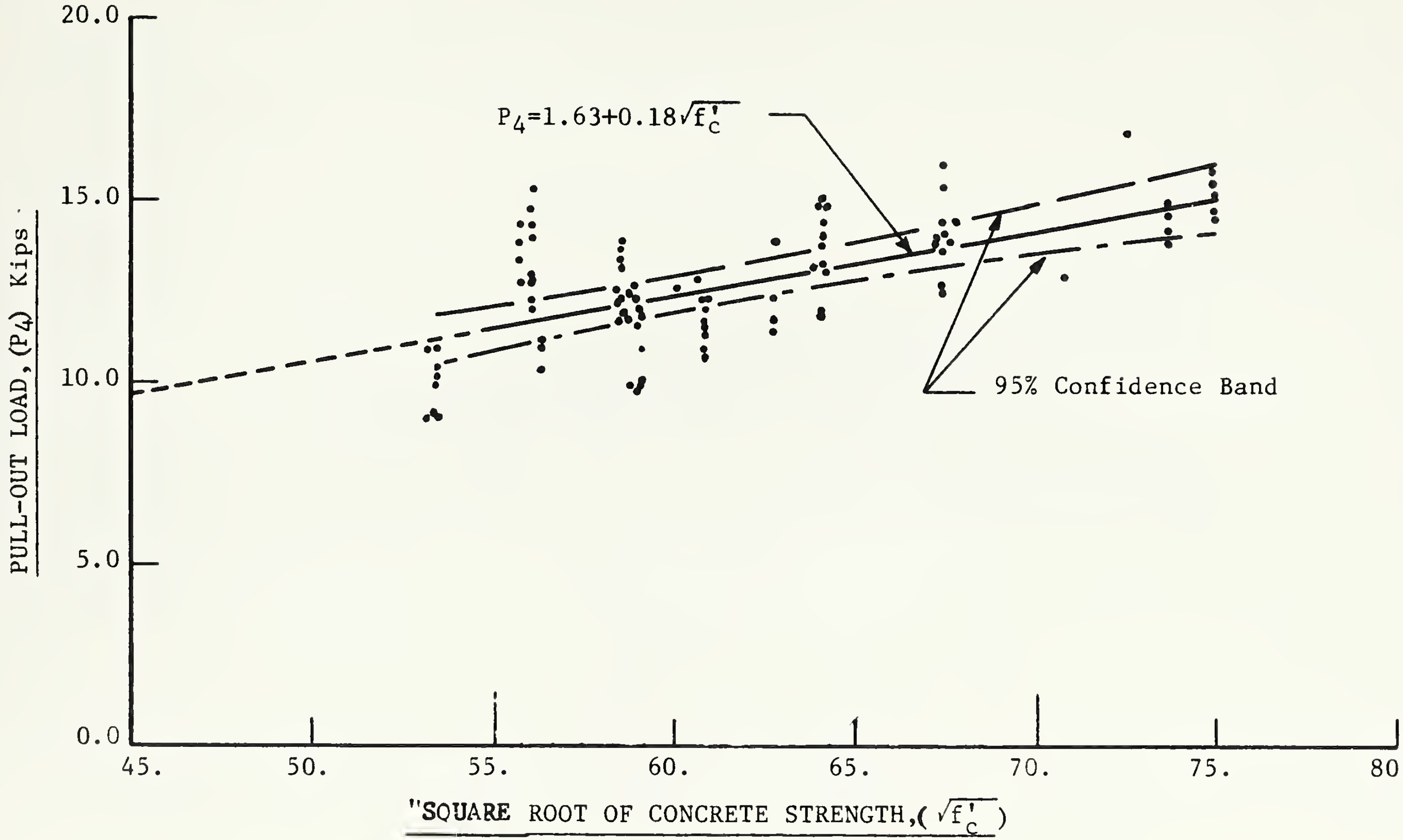

Fig. 16 - Normal Weight Concrete Strength Effect

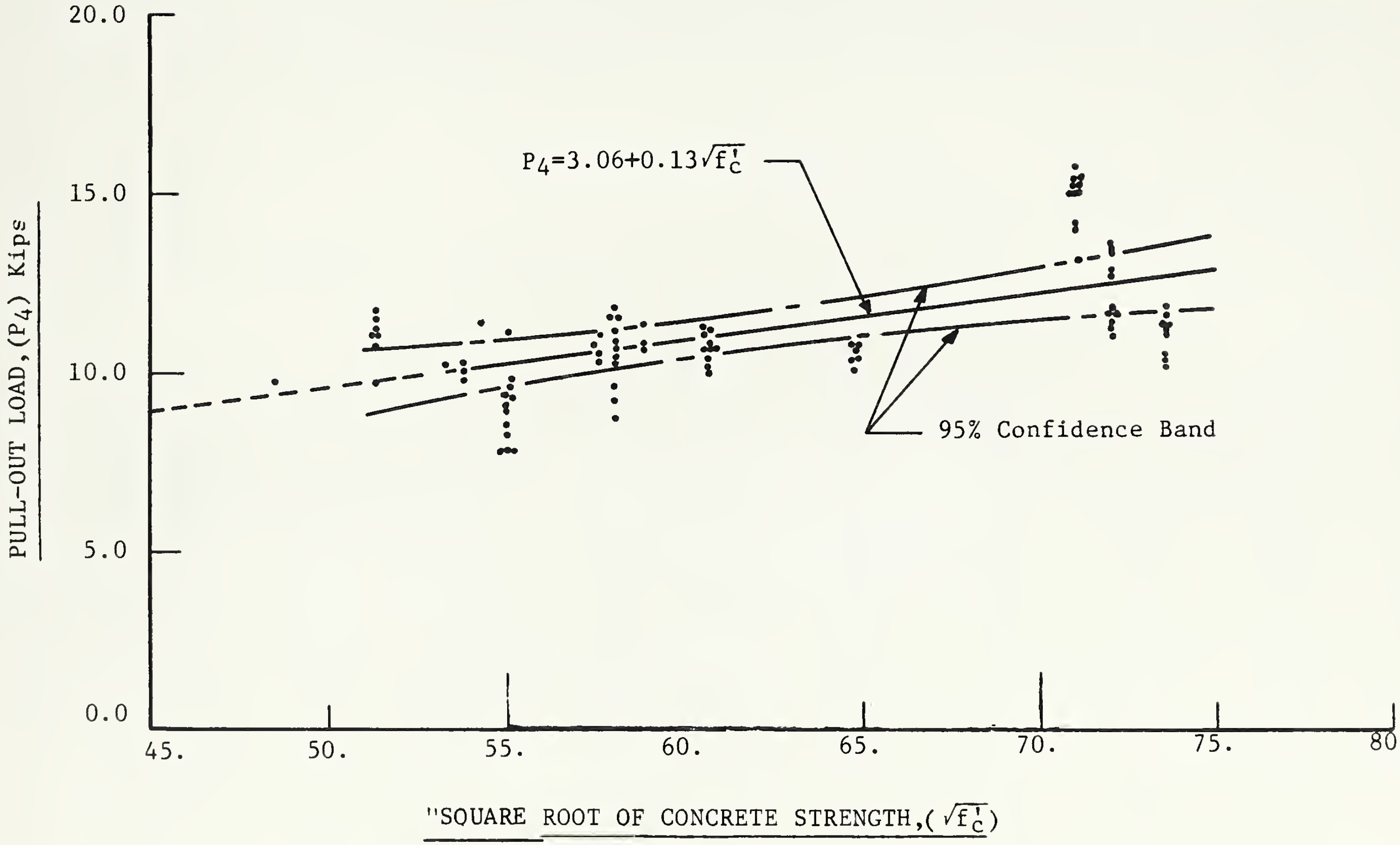

Fig. 17 - Semi-Lightweight Concrete Strength Effect

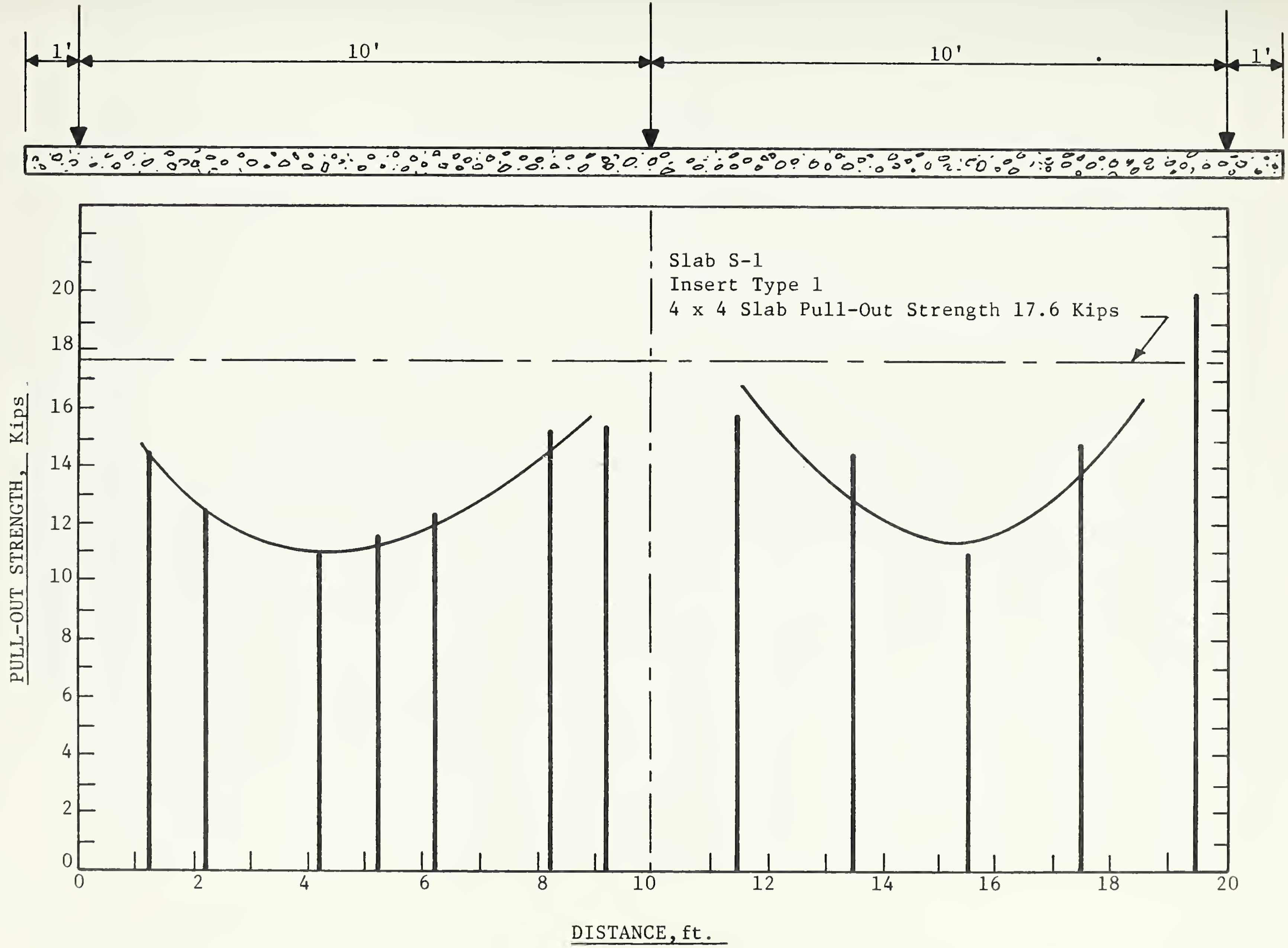

Fig. 18 - Pull-Out Strengths of Individual Inserts in Slab S-1

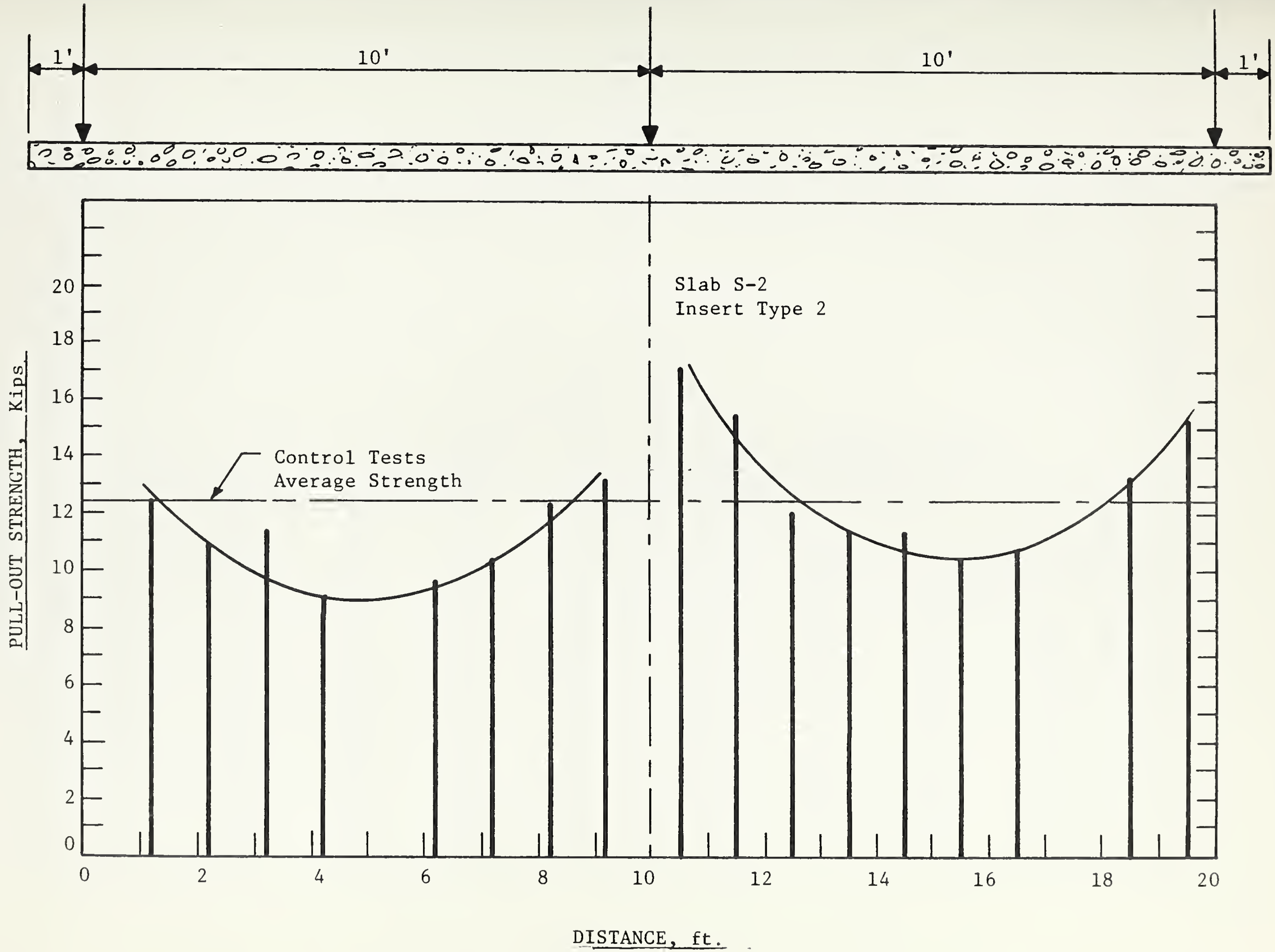

Fig. 19 - Pull-Out Strengths of Individual Inserts in Slab S-2

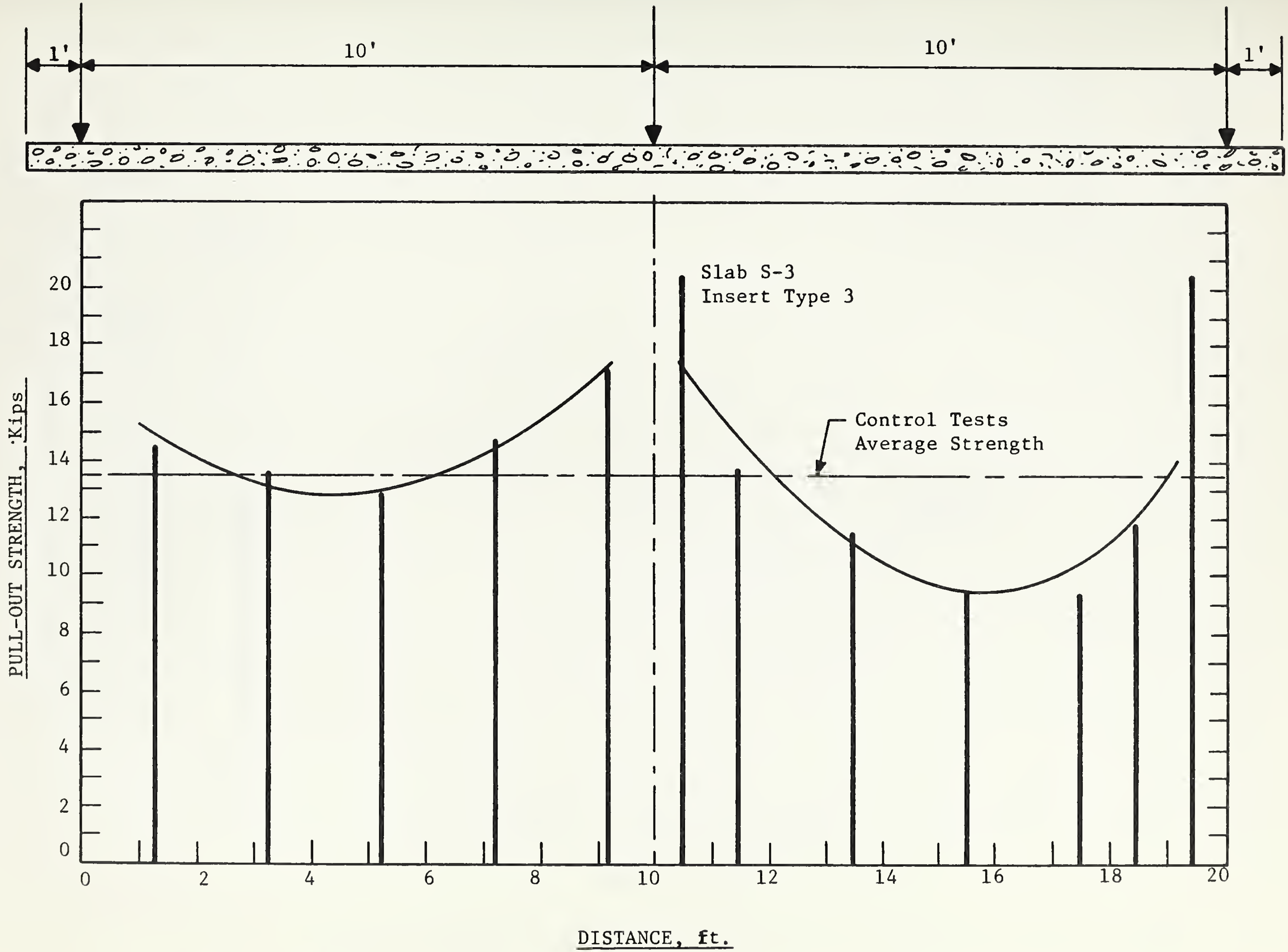

Fig. 20 - Pull-Out Strengths of Individual Inserts in Slab S-3

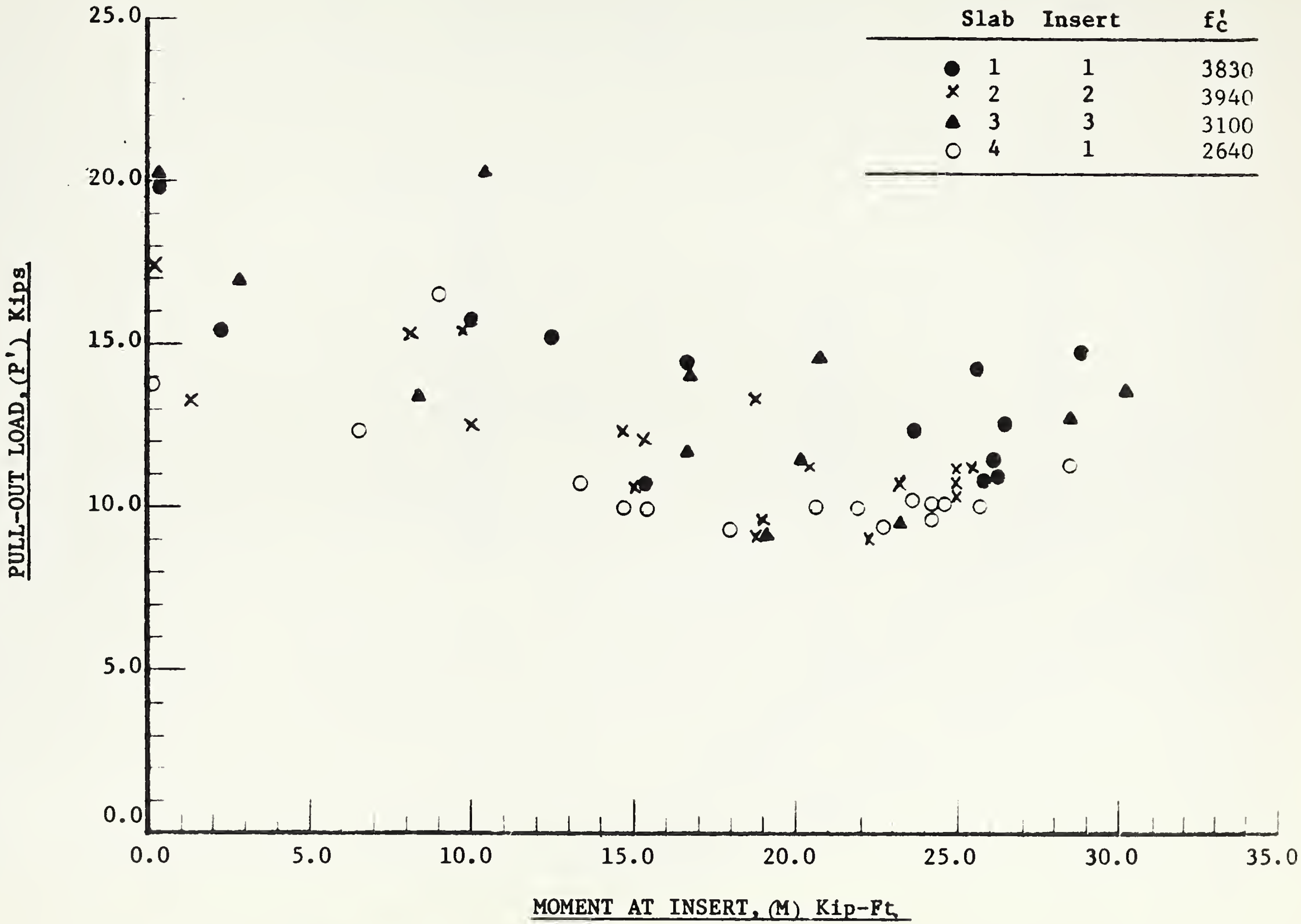

Fig. 21 - Pull-Out Strength vs. Moment for All Inserts in Continuous Slabs

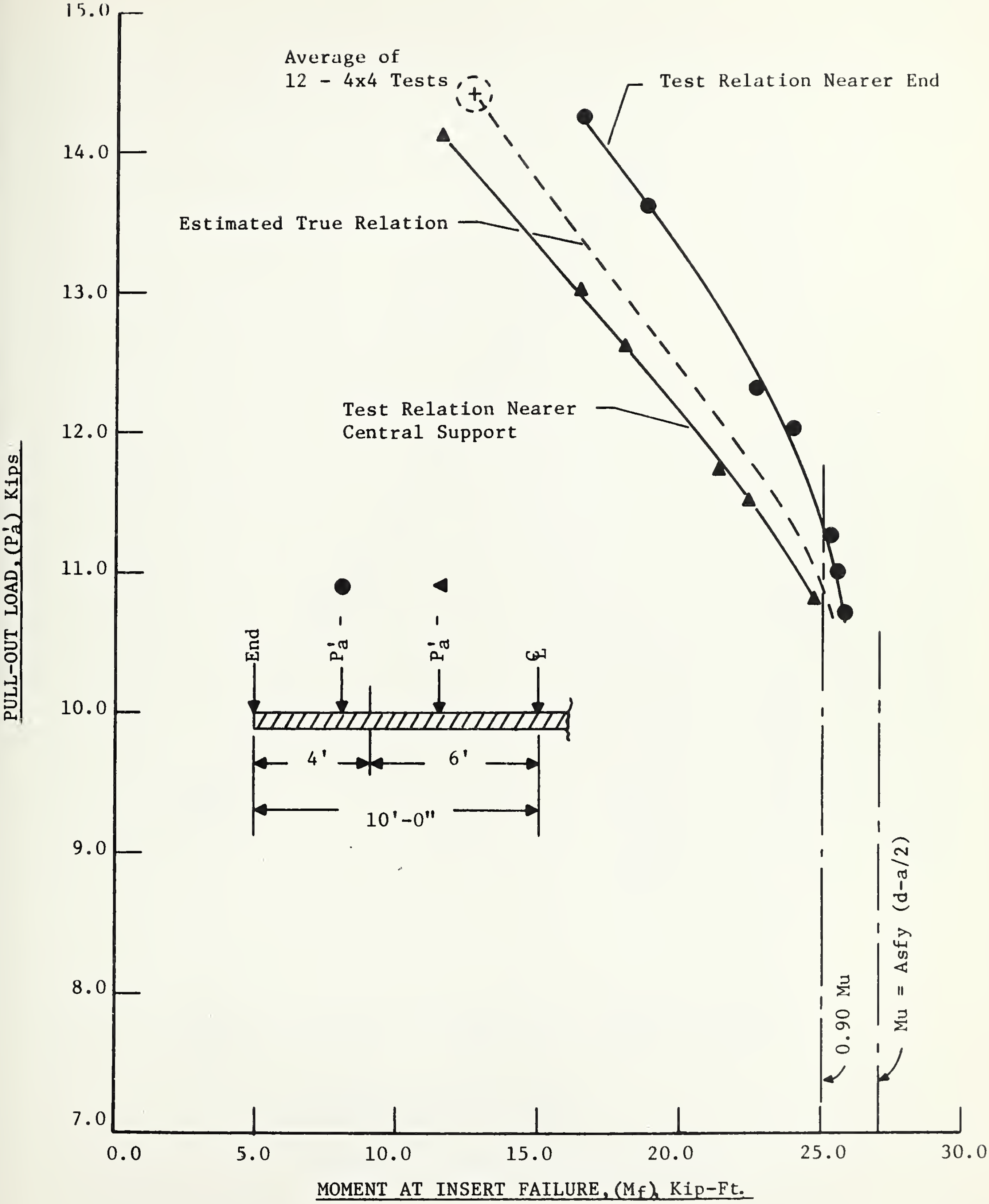

Fig. 22 - Pull-Out Strength vs. Moment

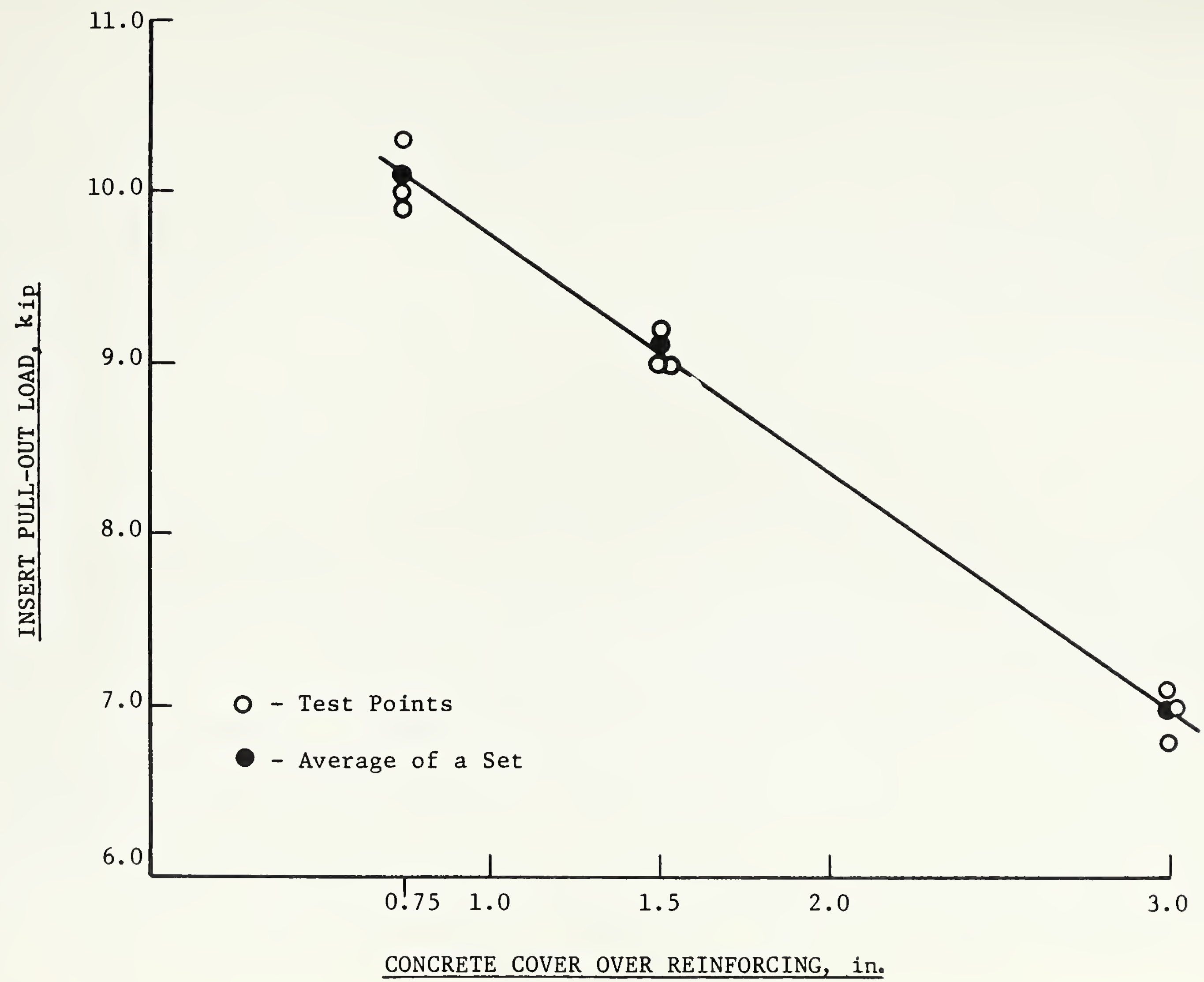

Fig. 23 - Pull-Out Load vs. Concrete Cover

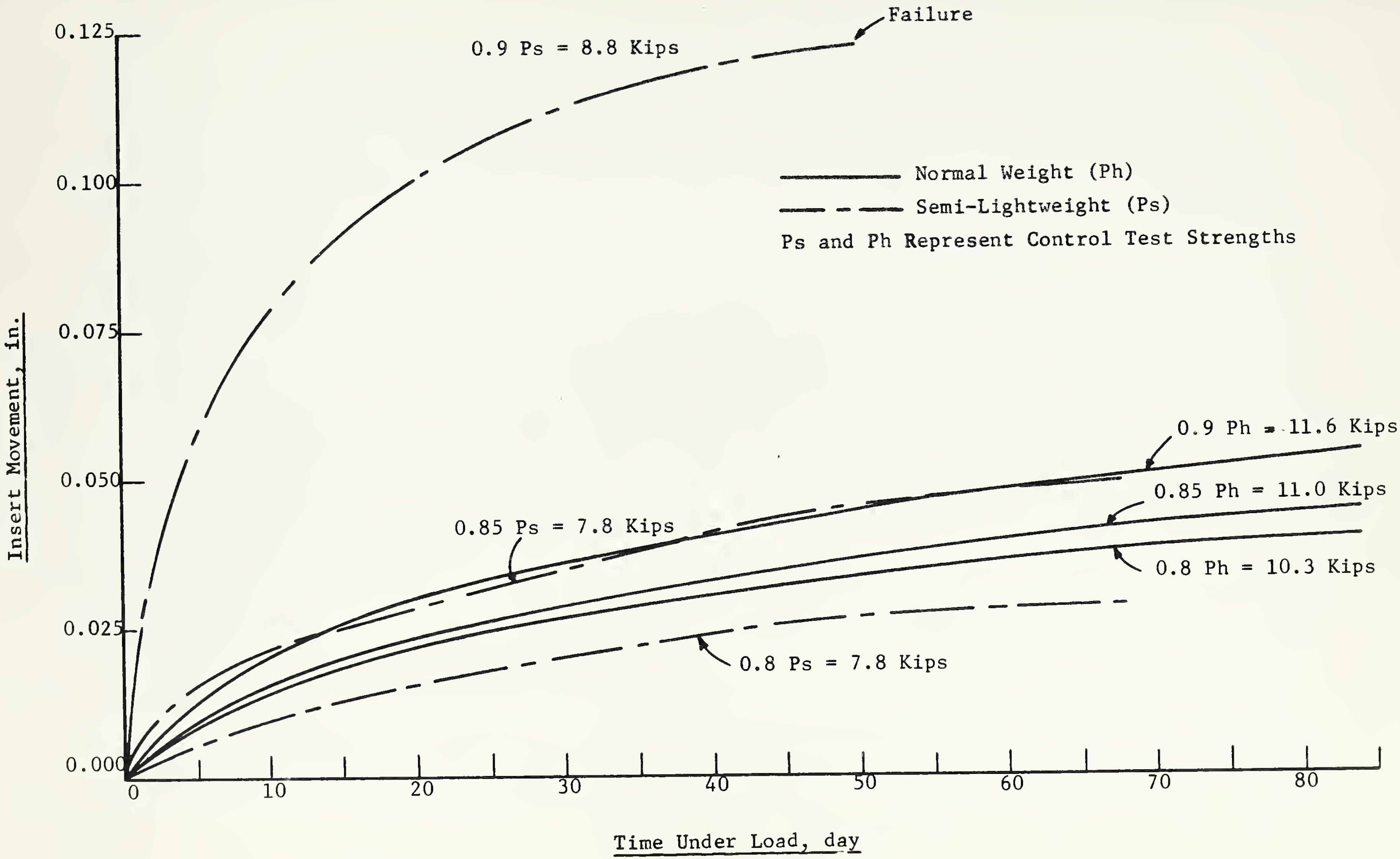

Fig. 24 - Sustained Load Tests

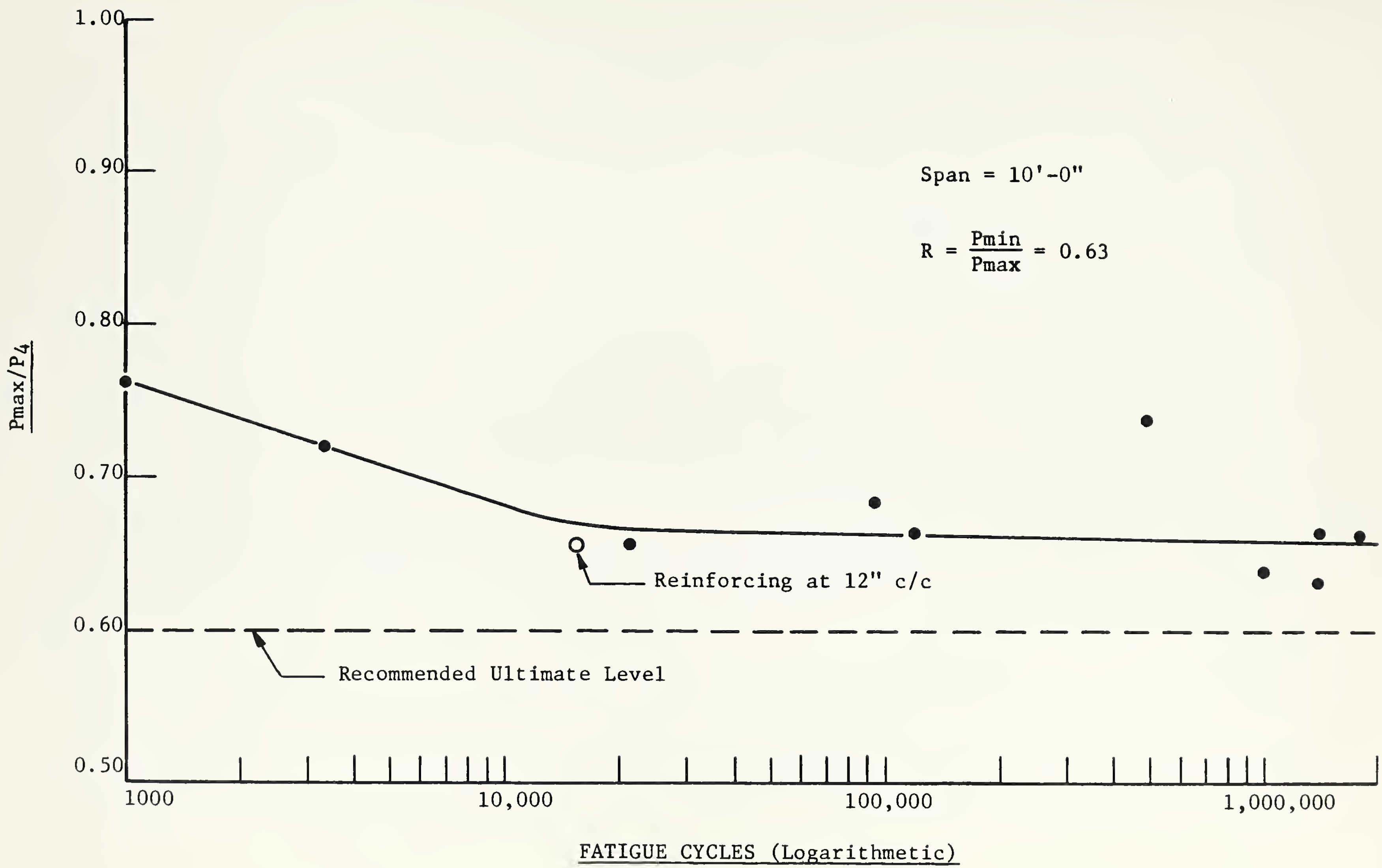

Fig. 25 - Normal Weight Concrete Fatigue Relations

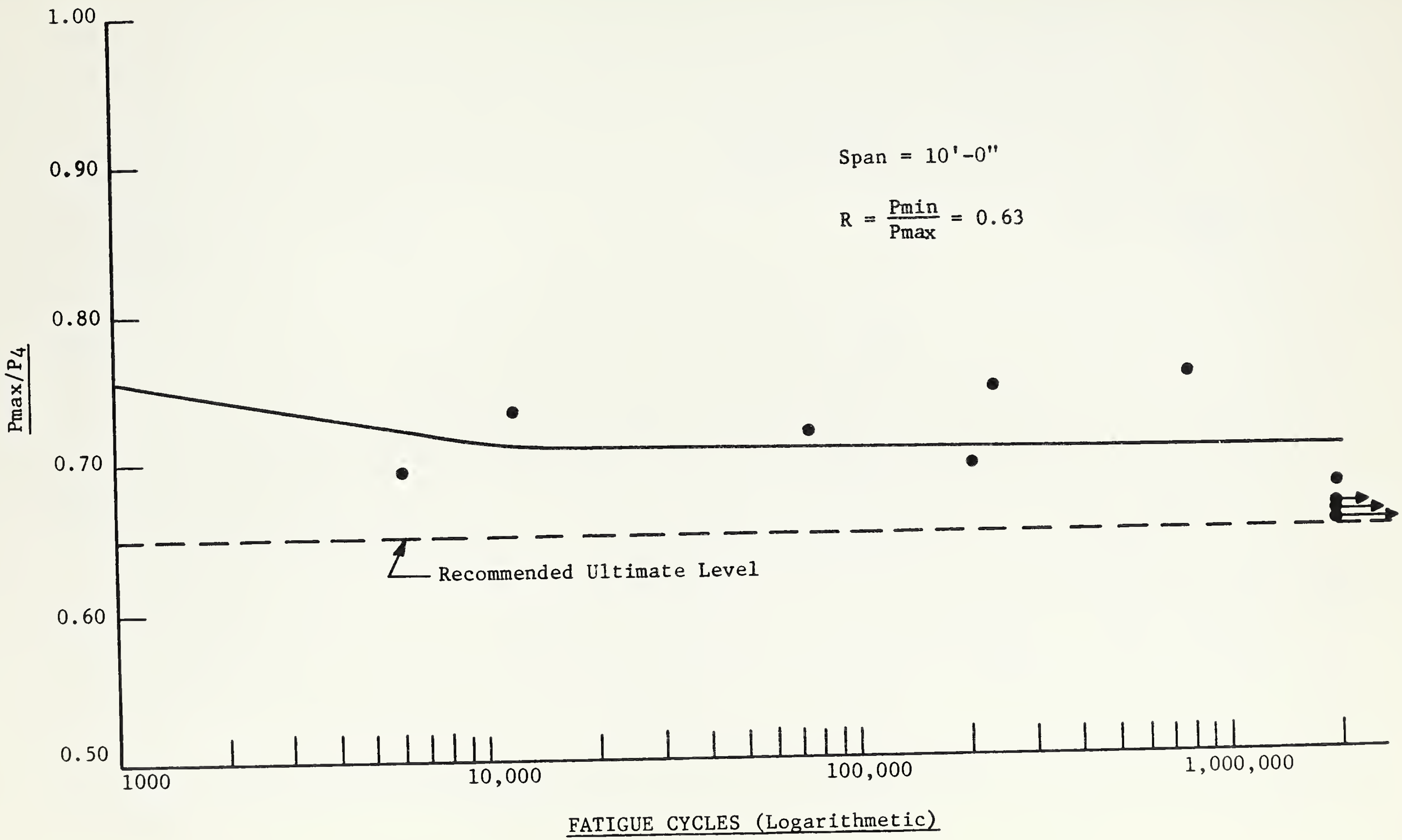

Fig. 26 - Semi-Lightweight Concrete Fatigue Relations

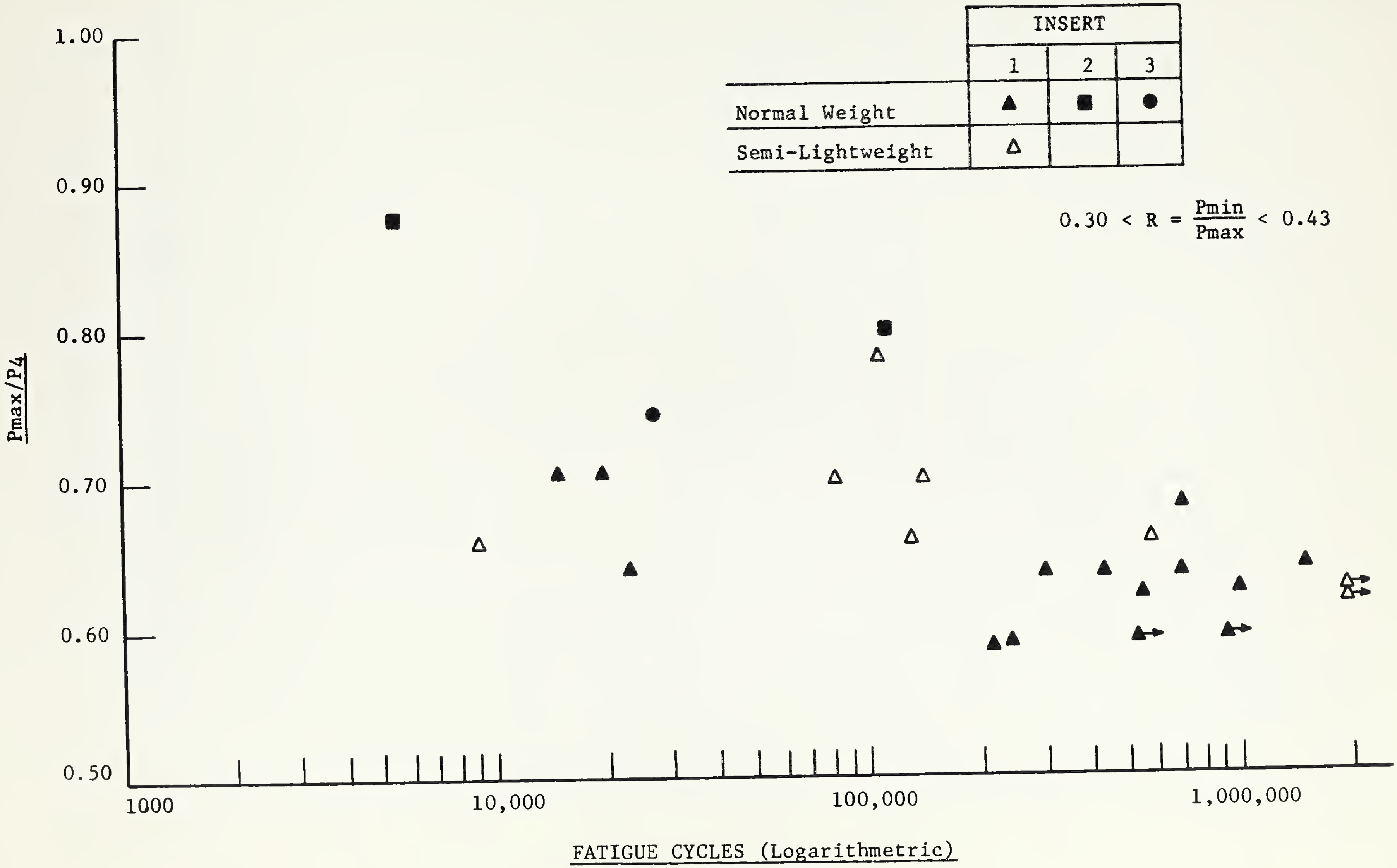

Fig. 27 - Fatigue Tests on 4x4 Samples

Fig. 28 - Histogram of All 4'x4' Tests

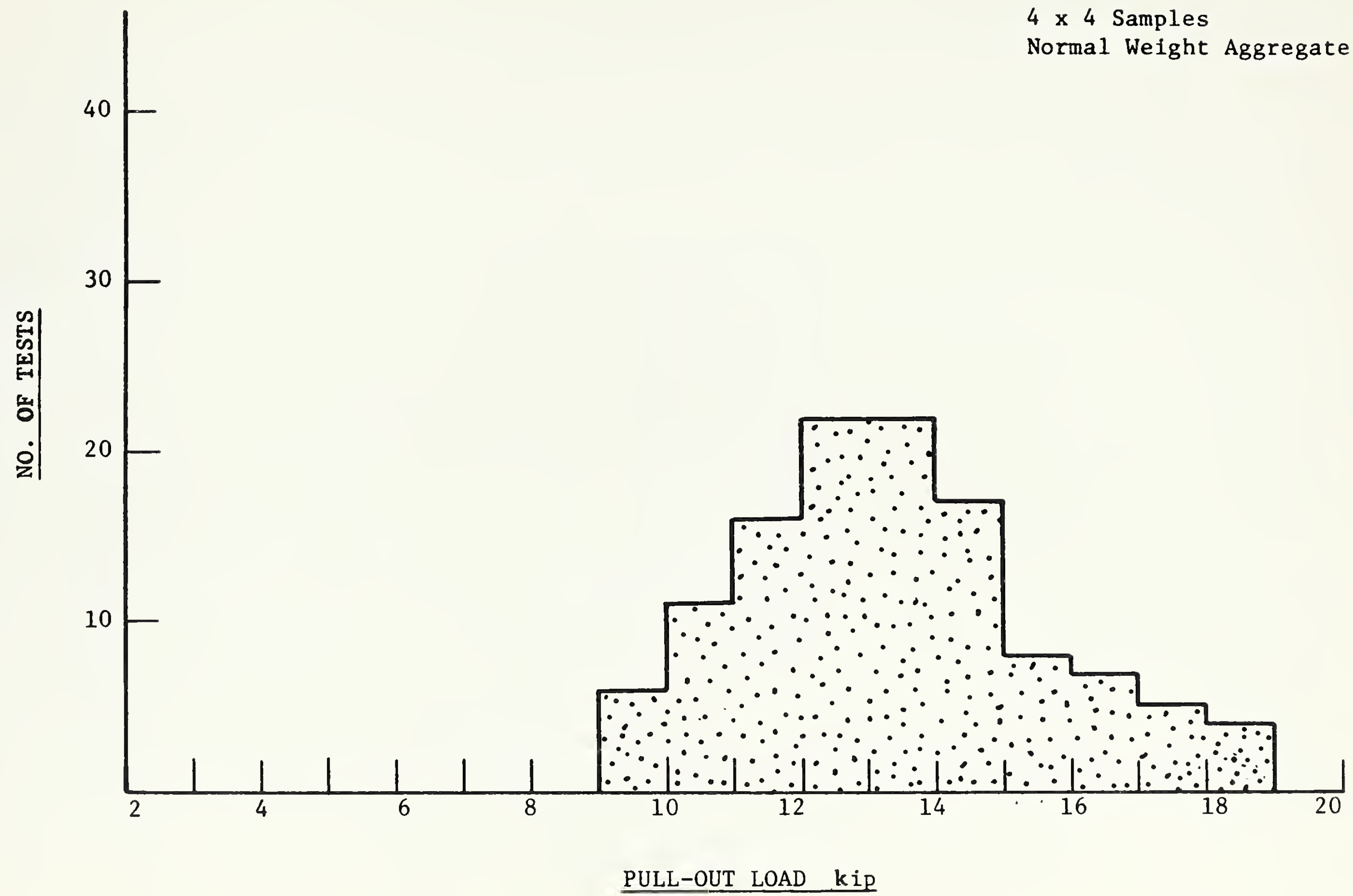

Fig. 29 - Histogram of all 4'x4' Tests

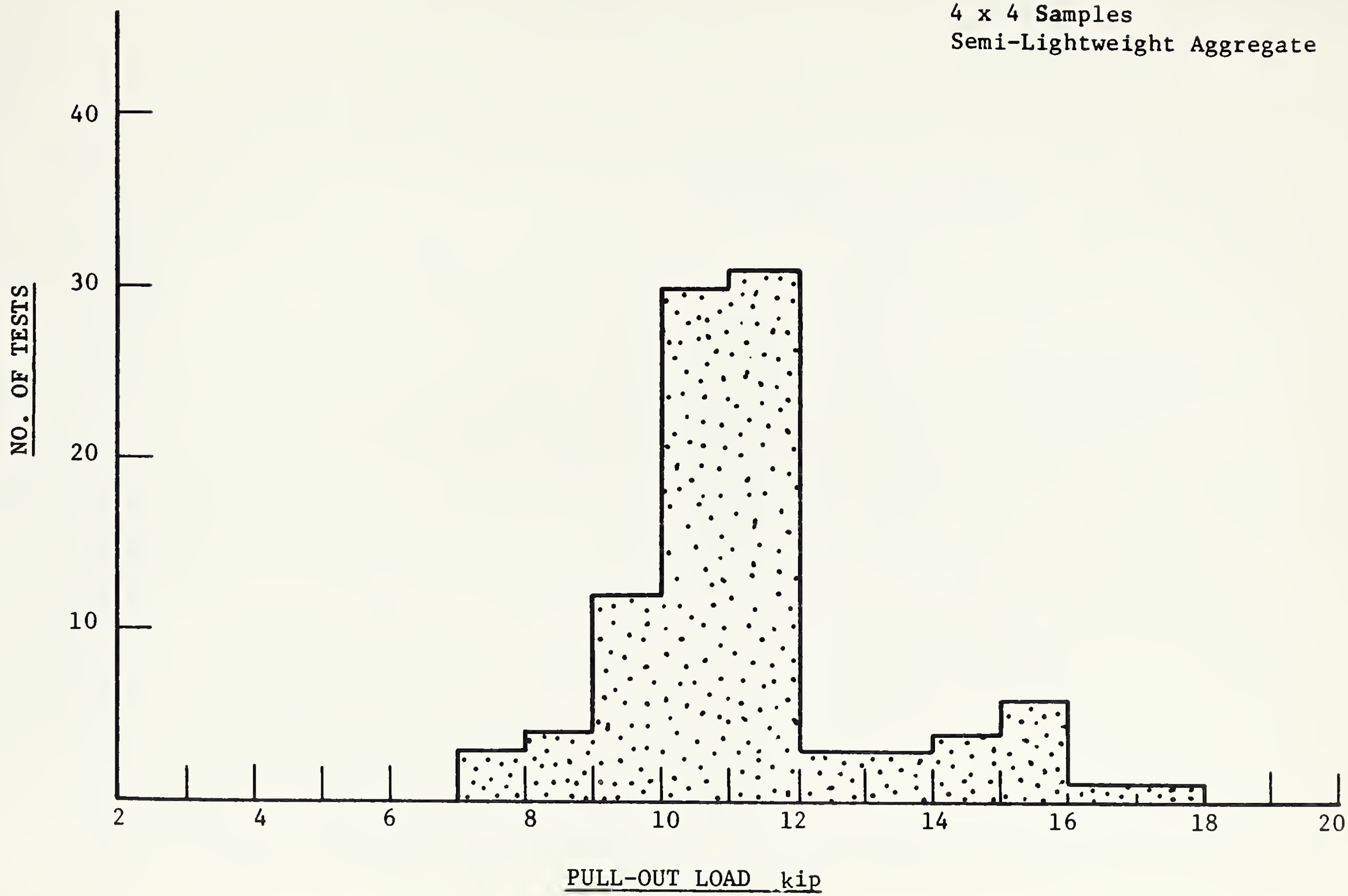

Fig. 30 - Histogram of all 4'x4' Tests

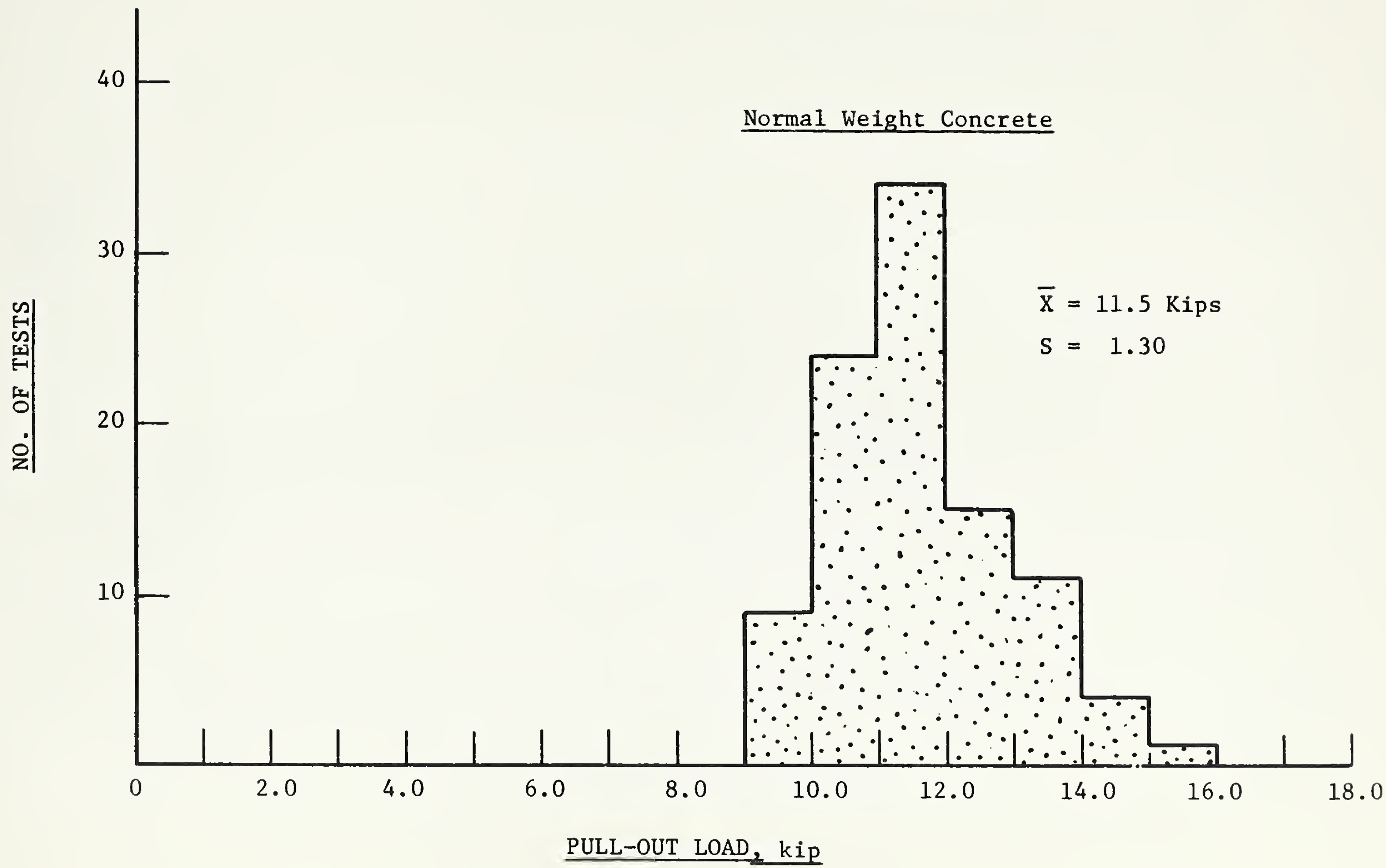

Fig. 31 - Histogram for Pull-Out Loads Normalized to Normal-Weight Concrete Compressive Strength of 3000 psi

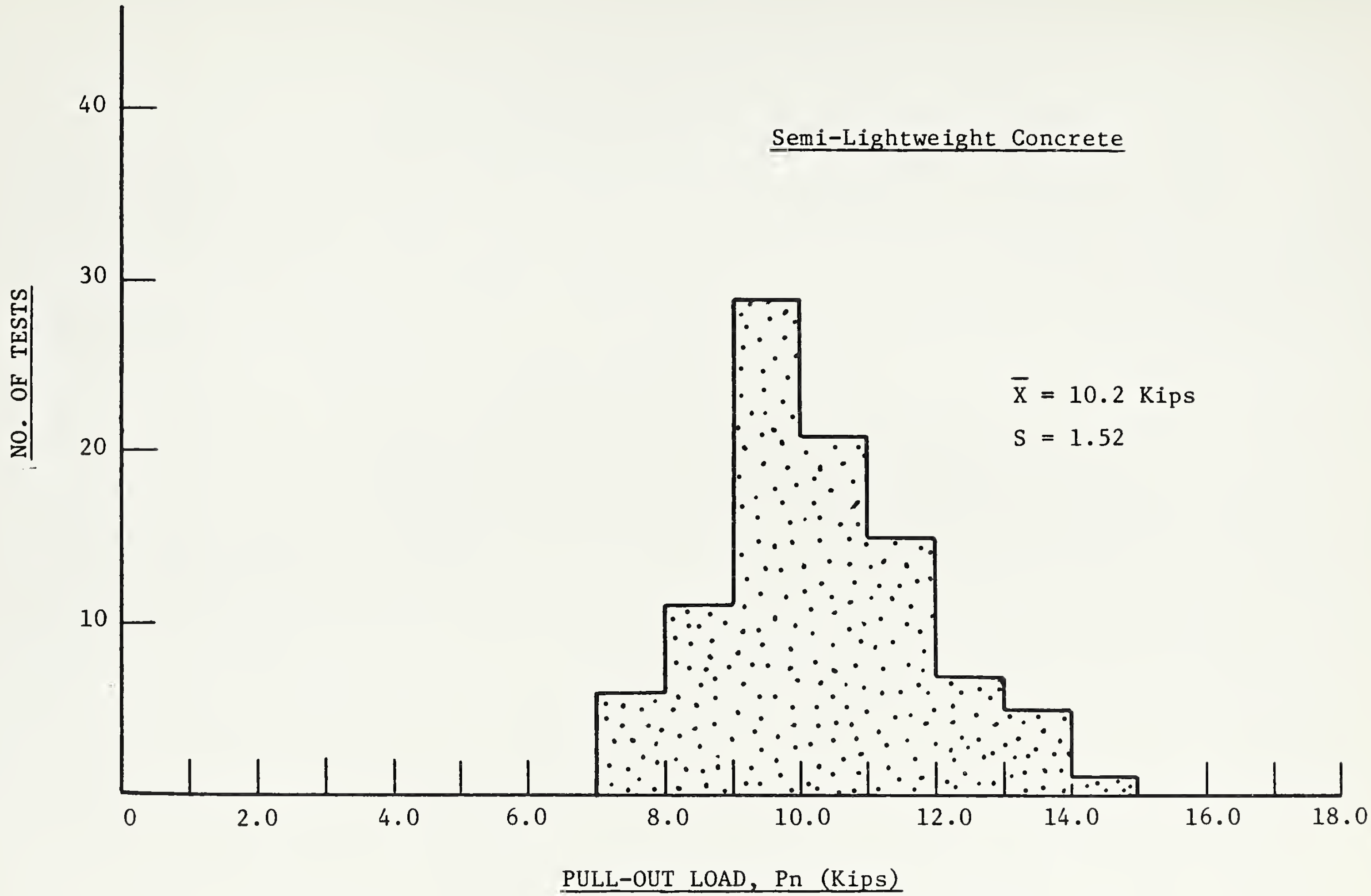

Fig. 32 - Histogram for Pull-Out Loads Normalized to Lightweight Concrete Compressive Strength of 3000 psi

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